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UNIVERSITY OF MAINE

Paper TRADE JOURNAL

LECTURES II

WOOD PULP

G

Established 1886

"The mark of wisdom is to read aright the present and to march with the occasion."
HOMER

Few eras in history have been so fraught with events of first magnitude and significance for man and for industry.

An accelerated Pulp and Paper Industry will continue "to march with the occasion," to resolve its problems and meet its responsibilities and advance with characteristic enterprise and ingenuity.

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— INCORPORATED —
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Machinery . . . paper-making equipment traditionally combining original design and extremes of size with high speed operation, precision and durability . . . implements a great industry.

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APPLETON WIRE WORKS, INCORPORATED • APPLETON, WISCONSIN

PULP MILLS have big stomachs...

Some folks call them digesters; some call them autoclaves or pressure cookers. They digest a belly-full of wood chips in the same way a man digests a beef steak—chemically and mechanically.

From that point forward papermaking is a succession of washings in clean water and of forming the beaten pulp into sheets. After the sheet has been formed the remaining water is pressed out through the open spaces between the threads of the felts and evaporated at the drier rolls.

You can't manufacture paper or board without felts. Every papermaker knows that. Most of them also know that you can't buy better felts than Hamiltons because no others remove water faster and none give finer finish to the sheets than Hamilton Felts.

Hamilton Felts

MIAMI WOOLEN MILLS

Established 1858

With more than 300 different styles from which to select, the Hamilton sales engineer is in position to suggest the best felt for your purpose.

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CARTHAGE BARKING DRUM

- ALL WELDED FULL LENGTH PLATE CONSTRUCTION
- NO RIVETS—BOLTS USED ONLY IN RING GEAR
- POUNDING ABSORBED BY WHOLE MASS OF DRUM
- SIMPLIFIED EIGHT BEARING CHASSIS
- 72″ TRUNNIONS

CARTHAGE MACHINE COMPANY

CARTHAGE, NEW YORK

Paper TRADE JOURNAL

NOVEMBER 14, 1952, *Vol. 135, No. 20*

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NEXT WEEK—*Consumers of waste paper will find enlightening data in Earle Weaver's "Waste Paper in Relations to the Paper Industry." As manager of purchasing for International, Mr. Weaver knows his subject.*

Also, E. Condict of De Laval Turbine Co., gives a short clear analysis to the problem of "Minimum Continuous Safe Flow of Centrifugal Pumps."

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REMEMBER THESE DATES

NOV. 18: Miami Valley Div., of the American Pulp and Paper Mill Superintendents Assn., Joint Meeting with the Ohio Section of TAPPI, American Legion, Middletown, Ohio.

NOV. 20-21: TAPPI Corrugated Container Conference, Schroeder Hotel, Milwaukee, Wis.

NOV. 20: Michigan Division, American Pulp and Paper Mill Superintendents Assn., Hotel Harris, Kalamazoo, Mich.

NOV. 21: New England TAPPI, Helen Kiely Night, Roger Smith Hotel, Holyoke, Mass.

DEC. 18: Michigan Division, American Pulp and Paper Mill Superintendents Assn., Hotel Harris, Kalamazoo, Mich.

Feb. 15-20, 1953: APPA, Annual Meeting, Waldorf-Astoria Hotel, New York, N. Y.

Feb. 16-17, 1953: Salesmen's Assn., of the Paper Industry, Annual Meeting, Waldorf-Astoria Hotel, New York, N. Y.

FEB. 16-19, 1953: TAPPI, Annual Meeting, Commodore Hotel, New York, N. Y.

JUNE 9-11, 1953: APPMSA, National Meeting, Atlanta-Biltmore Hotel, Atlanta, Ga.

International Paper Company is a large user of Huber Filler Clays

International Paper Company's wide range of papers fills most of modern industry's paper requirements. And International knows that the quality of its products depends on the quality of all its raw materials. That's why International turns to J. M. Huber as a major source of supply for its filler clay needs.

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HYDRATEX—a Georgia coating grade of medium particle size distribution and priced accordingly. Quality controlled throughout. Lump or pulverized.

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X-43—a fine particle Georgia coating clay of low viscosity and high brightness particularly well adapted to high solids coating. Lump or pulverized.

X-44—a low viscosity Georgia coating grade containing a minimum of soluble salts; excellent for color pigmentation. Lump or pulverized.

HYDRASPERSE—a drum-dried low viscosity, high brightness, fine particle, Georgia coating grade, in flake form, with the dispersant already added. Saves "make down" time and assures thorough dispersion in practically any equipment.

*1. Brightness 2. Viscosity 3. Particle Size 4. pH 5. Screen Residue 6. Adhesive Demand 7. Gloss 8. Opacity 9. Dispersion 10. Soluble Salts 11. Abrasion 12. Moisture 13. Suspension

FOR HIGH WET STRENGTH AT LOW COST

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A New Cationic Resin

Where high wet strength is needed at low cost—as in bag stock, toweling, and a host of other uses—UFORMITE 711 is your answer. This new modified urea formaldehyde resin imparts wet strength, and improves dry tensile, mullen, fold, pick resistance, and wet rub. It is adaptable to a wide variety of pulps from Kraft to sulfite-groundwood combinations.

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7. Stability in storage.

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THE RESINOUS PRODUCTS DIVISION

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Rohm & Haas makes a complete range of dependable wet-strength resins:—UFORMITE 700, cationic resin for fast wet strength off the machine —UFORMITE 467, liquid anionic type for efficient, low-cost wet strength, particularly suitable for beater addition—UFORMITE 520, powdered anionic type corresponding to UFORMITE 467—and UFORMITE 471, liquid cationic type, suitable for all furnishes, any addition point. We'll be glad to mail you literature on these UFORMITE resins, also.

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PROCESSED IN OUR HIGHLY EFFICIENT PLANT

at
SANDERSVILLE,
GEORGIA . . .

Aerial view of Thiele plant

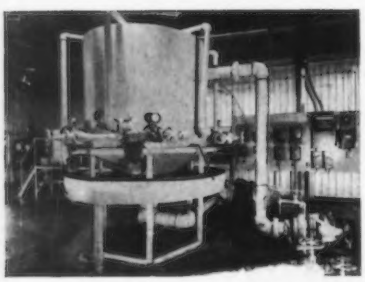
Thiele Kaolin

View of mine

WATER-WASHED

PAPER COATING and FILLER CLAYS...

possess excellent color, fine particle size and low viscosity.



Mixing Equipment at mine

Storage of clay slurry at mine

Piping Station on 9-mile pipeline

Our water-washed clays obtained from our enormous holdings in the Georgia clay belt, are serving a great and growing number of the country's leading paper manufacturers.

Write for sample of Thiele Kaolin Clay for your particular use.

Thiele Kaolin Company

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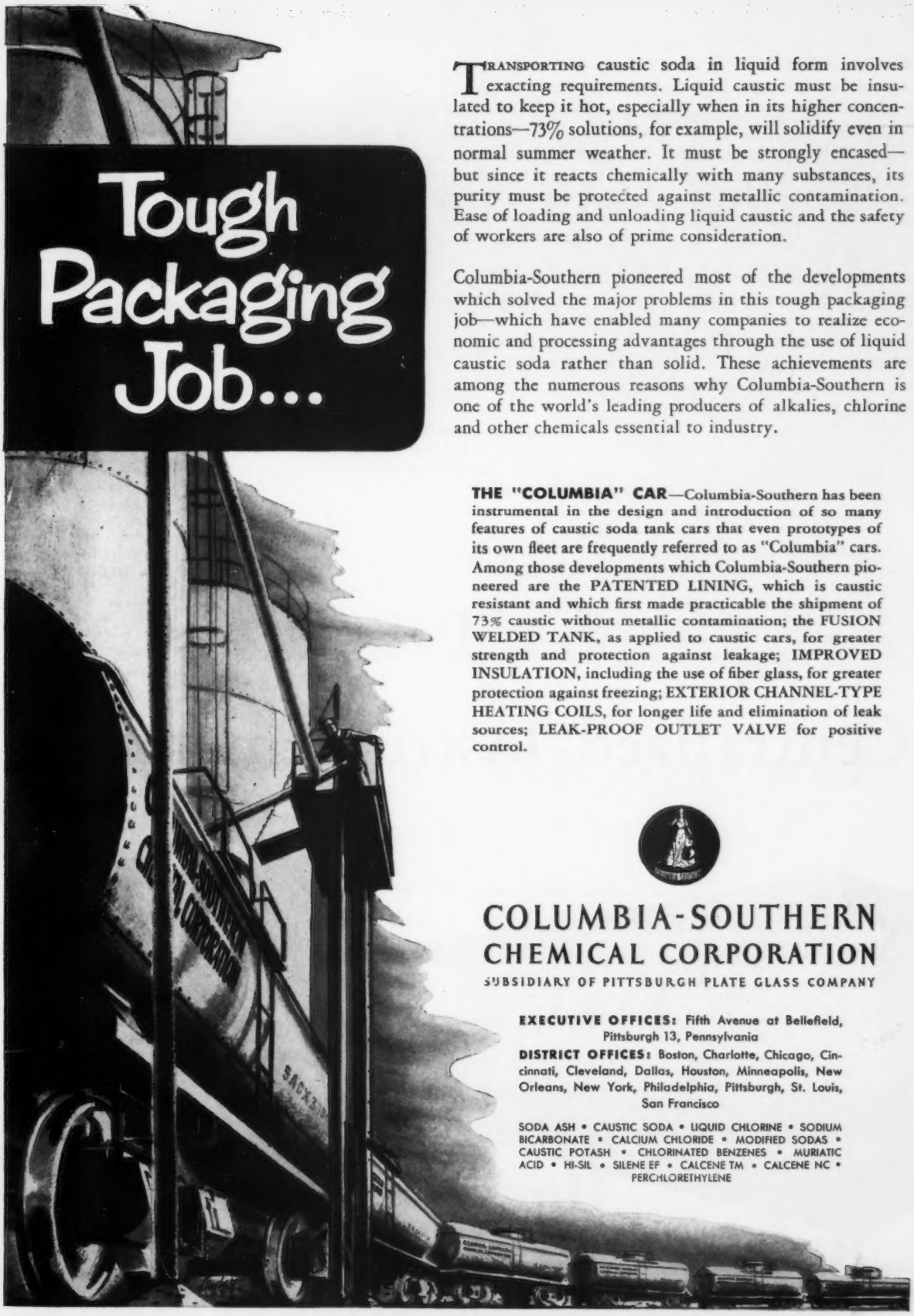

TRANSPORTING caustic soda in liquid form involves exacting requirements. Liquid caustic must be insulated to keep it hot, especially when in its higher concentrations—73% solutions, for example, will solidify even in normal summer weather. It must be strongly encased—but since it reacts chemically with many substances, its purity must be protected against metallic contamination. Ease of loading and unloading liquid caustic and the safety of workers are also of prime consideration.

Columbia-Southern pioneered most of the developments which solved the major problems in this tough packaging job—which have enabled many companies to realize economic and processing advantages through the use of liquid caustic soda rather than solid. These achievements are among the numerous reasons why Columbia-Southern is one of the world's leading producers of alkalies, chlorine and other chemicals essential to industry.

THE "COLUMBIA" CAR—Columbia-Southern has been instrumental in the design and introduction of so many features of caustic soda tank cars that even prototypes of its own fleet are frequently referred to as "Columbia" cars. Among those developments which Columbia-Southern pioneered are the PATENTED LINING, which is caustic resistant and which first made practicable the shipment of 73% caustic without metallic contamination; the FUSION WELDED TANK, as applied to caustic cars, for greater strength and protection against leakage; IMPROVED INSULATION, including the use of fiber glass, for greater protection against freezing; EXTERIOR CHANNEL-TYPE HEATING COILS, for longer life and elimination of leak sources; LEAK-PROOF OUTLET VALVE for positive control.

COLUMBIA-SOUTHERN
CHEMICAL CORPORATION
SUBSIDIARY OF PITTSBURGH PLATE GLASS COMPANY

EXECUTIVE OFFICES: Fifth Avenue at Bellefield, Pittsburgh 13, Pennsylvania

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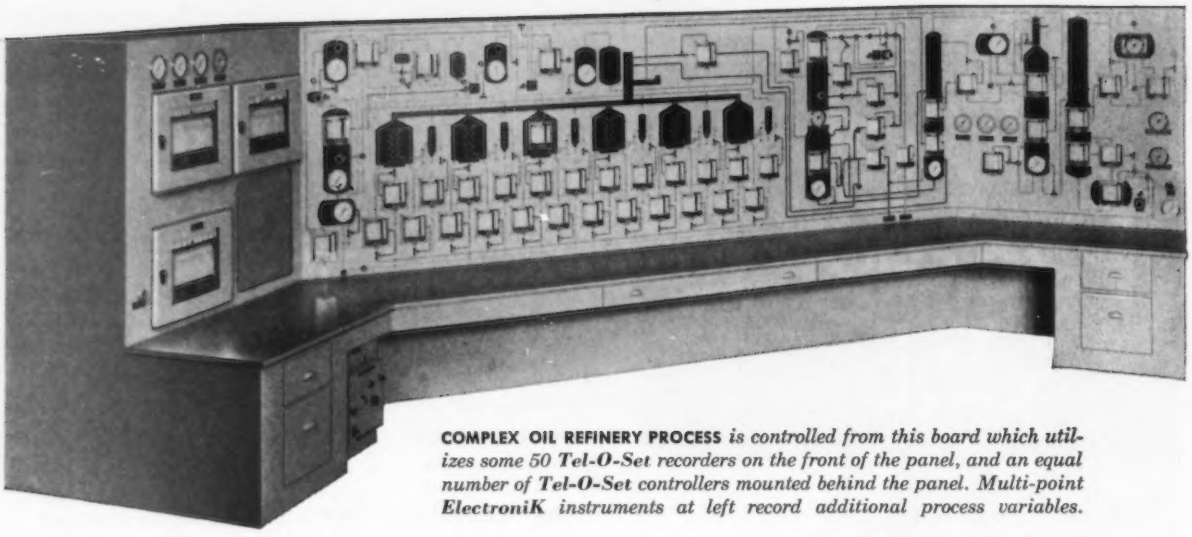
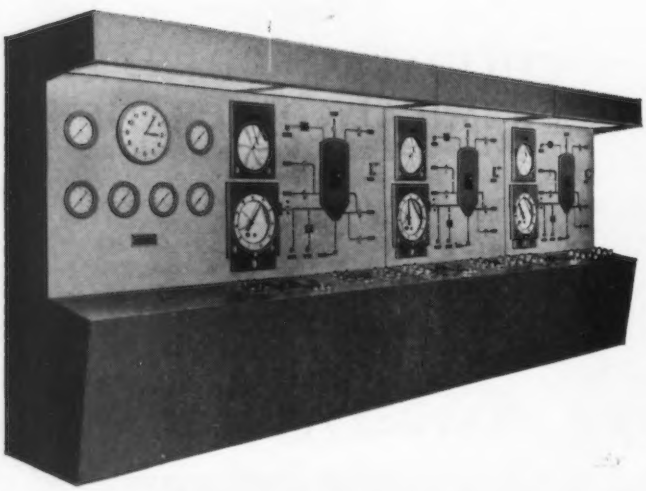
SODA ASH • CAUSTIC SODA • LIQUID CHLORINE • SODIUM BICARBONATE • CALCIUM CHLORIDE • MODIFIED SODAS • CAUSTIC POTASH • CHLORINATED BENZENES • MURIATIC ACID • HI-SIL • SILENE EF • CALCENE TM • CALCENE NC • PERCHLORETHYLENE

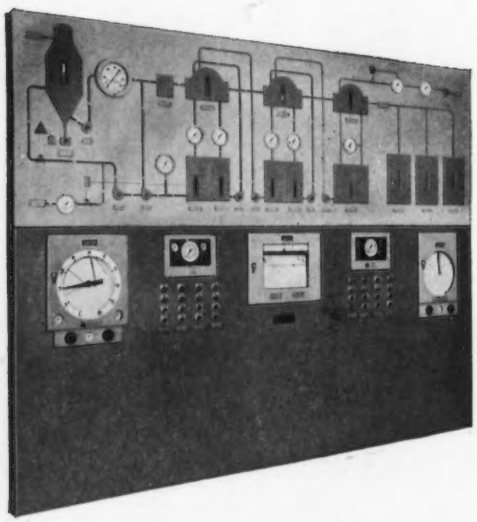


COMPLEX OIL REFINERY PROCESS *is controlled from this board which utilizes some 50* ***Tel-O-Set*** *recorders on the front of the panel, and an equal number of* ***Tel-O-Set*** *controllers mounted behind the panel. Multi-point* ***ElectroniK*** *instruments at left record additional process variables.*

Graphic Panels for Centralized Instrumentation...



CHEMICAL PLANT *panel combines the graphic theme with conventional size controlling instruments. It is built as a vapor-tight cubicle with a console front and overhanging light canopy.*



PAPER MILL *panel utilizes color to facilitate identification of process components . . . was designed by Honeywell engineers in close cooperation with the mill's engineers.*

PANEL PRODUCTION *in Honeywell's extensive shop devoted exclusively to panel work—utilizes the skills of highly trained specialists. All instruments, controllers, accessories, and back of panel wiring, and piping are carefully assembled—then subjected to rigorous tests to assure trouble-free installation and start-up when the panel reaches your plant.*

. . . *a progress report from Honeywell*

SHOWN here are just a few of the many graphic instrument panels which Honeywell has supplied for centralized control of a wide variety of industrial processes. Each one is the result of well-seasoned engineering know-how . . . based on extensive Honeywell experience . . . which combines all instruments and accessories into a closely integrated, efficient design.

Whether your process calls for a full graphic or semi-graphic panel . . . a conventional board . . . or a control cubicle . . . you can be sure of obtaining every feature of quality and performance that you need in a Honeywell panel.

In Honeywell's Panel Division, meticulous attention to engineering detail and highly developed construction techniques watch over every step—from blueprint to assembly to final test. Add to this engineering and manufacturing skill the availability of a complete line of conventional and miniature instruments, and the result is a control board . . . custom-fitted to *your* needs . . . that makes *Panels by Honeywell* synonymous with the best in centralized control.

Our local engineering representative will be glad to discuss how graphic panels by Honeywell can bring new efficiency to your processes. Call him today . . . he is as near as your phone.

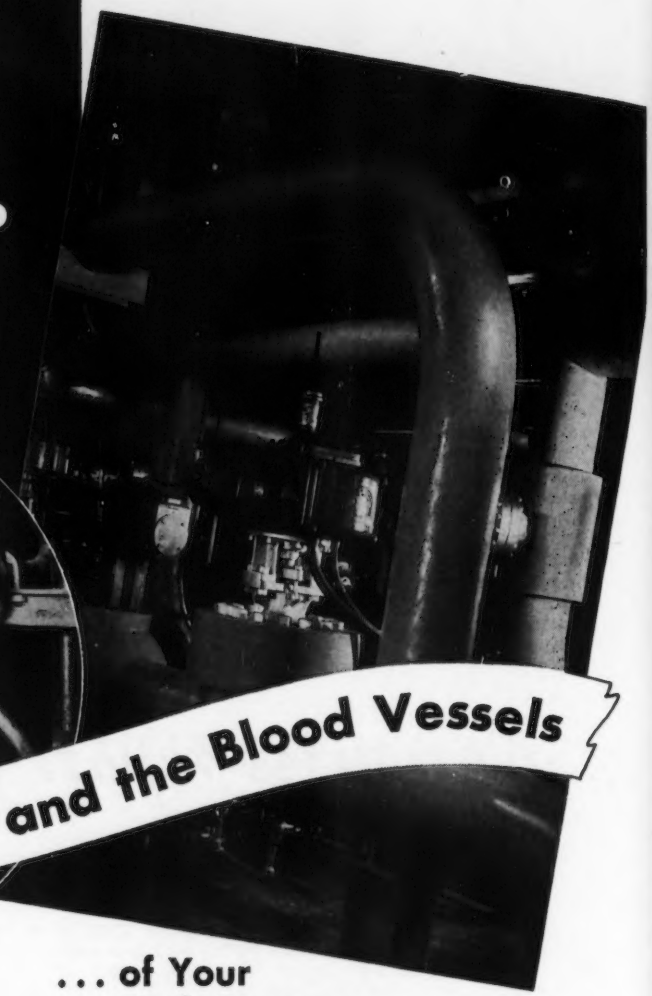
MINNEAPOLIS-HONEYWELL REGULATOR CO., *Industrial Division*, 4510 Wayne Ave., Philadelphia 44, Penna.

MINNEAPOLIS
Honeywell
BROWN INSTRUMENTS
First in Controls

● *Important Reference Data*

Write for your copy of Bulletin No. 85-20, "Centralized Instrumentation . . . unlimited."

LONG LIFE IS ASSURED WHEN P.P.&E. *Produces...*



the Nerves, and the Blood Vessels ... of Your High Pressure High Temperature Piping System

The blood-vessels (main lines) and the nerves (control lines) of a power piping layout are equally essential to keep the entire system "full of steam."

And — the material from which the piping is made — and the way it is put together — will determine the efficiency and longevity of the system.

It's possible for a strong man to be a "physical wreck" because of a deficiency in his nervous system — and it's just as possible for a power plant to perform erratically because of inefficient engineering and installation of accessory piping.

P.P.&E. is just as careful to build sound "nerves" into a power piping system as it is to provide strong "blood vessels."

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The difference is high sizing efficiency... using less size!

...when you specify Cyanamid's CYFOR* Rosin Size
a new "fortified" size with superior qualities

In most cases where high sizing tests are specified, CYFOR Rosin Size can offer you economies by meeting these requirements with exceptionally low size addition. This cut in size added may be up to 50% in many instances and will give you *dollar* savings. As an "extra", you will find non-variable sizing tests, uniformity of operation and better machine conditions due to less size in the system—better paper qualities with less size in the sheet.

Another advantage of equal importance is the ability to attain with CYFOR Rosin Size those "difficult" specs that are just "out of range" for ordinary sizes. No more excessive addition of size to complicate machine operation—reach those specs easily with CYFOR. Achieve . . .

higher lactic acid resistance on milk bottle board
higher ink test on writing and printing papers
higher water resistance in food containers, butcher wrap, ice-cream pail, off-set printing stock and coated raw stock

For further information showing the excellent performance of Cyanamid's CYFOR Rosin Size just call in a member of Cyanamid's Technical Service Staff.

Cyanamid Paper Chemicals: ALWAX* Sizes • WAXINE® Sizes • ACCOCEL* Dispersants • ACCOBRITE® Rosin Size • PAREZ® Resins • Casein • Sulfonated Oils • Fillers • Defoamers • Soda Ash • Caustic Soda • Salt Cake • Acids Clays • AEROSOL® Wetting Agents • CALMICRO® • Calcium Carbonate AZITE® 900 Liquefier • Aluminum Sulfate • Sodium Phospho Aluminate.
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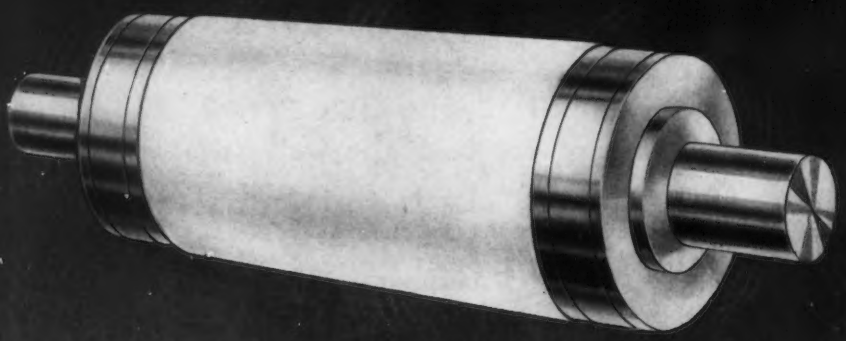
"HOLYOKE"
CALENDER ROLLS



HOLYOKE MACHINE COMPANY

CALENDER ROLLS for the PAPER and TEXTILE INDUSTRIES
WATER FILTRATION EQUIPMENT
HOLYOKE, MASSACHUSETTS

GROWING ASSURANCE

of a future supply of WEYERHAEUSER WOODPULP

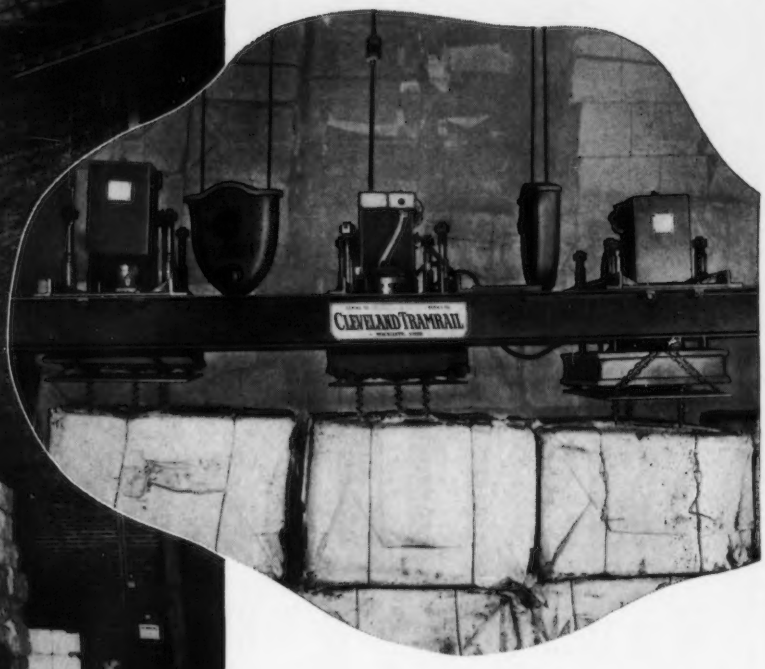
As early as 1911, Weyerhaeuser Timber Company had plans to consolidate and hold large blocks of timber land for the growing of future timber crops. In 1924, the company employed experienced foresters to work out the details of these plans.

During the mid-thirties the development of a broad forestry policy proceeded at an increased pace. In 1941, the Clemons tree farm was established as the first of its kind. Thus began a nation-wide movement which recognized the fact that private owners of forest land could and must manage their lands for continuous production of forest crops according to sound forestry principles. Now, there are over 25,000,000 acres of such farms located in 35 different states.

Today, all of the Weyerhaeuser Timber Company's operating forest lands are divided into eleven tree farms containing over 2,500,000 acres of timber land. With a background of half a century in the timber business, Weyerhaeuser is now projecting its sustained yield forestry policy 100 years ahead! This is part of the company's *permanent production program* designed to provide a continuing and *increasing* timber supply for its mills.

SCREW GRAB REDUCES PULP HANDLING COSTS

200 TONS EASILY HANDLED PER 8-HOUR DAY AT GREATLY REDUCED COST



BALES PILED 35 FT. HIGH

The crane at left equipped with motor-operated screw grab above handles 3 bales at a time. All motions of crane and grab are controlled by operator in crane cab. This building has 5000 tons capacity and is 160'-0" x 50'-0" x 45'-0" truss height.

Man-hours spent handling bales of pulp are greatly reduced when a Cleveland Tramrail overhead crane and screw grab are used. And more pounds are stored per square foot, because no aisleways are required and also because of high piling. Safety is improved.

As a result, great savings are made on both warehousing and handling of pulp. Equipment like this pays for itself in a surprisingly short time. Let us give you details.

GET THIS BOOKLET!

Gives details on a 5000 ton and a 1100 ton pulp warehouse.

CLEVELAND TRAMRAIL DIVISION
THE CLEVELAND CRANE & ENGINEERING CO.
7117 East 287th Street, Wickliffe, Ohio

CLEVELAND TRAMRAIL
OVERHEAD MATERIALS HANDLING EQUIPMENT

On more than 23 million acres of privately owned forest lands, men are growing and harvesting timber as a crop. The owners of these tree farms are pledged to protect their timber from fire, insects and disease . . . thus assuring crop after crop of trees for use in wood products for you and your children.

In the Northwest, timber owners are actively combatting the ravages of the spruce budworm. One large-scale program in the States of Washington and Oregon has conserved more than 40 billion board ft. of otherwise doomed timber.

Aerial spraying of insecticide did the job. This Pennsalt-produced insecticide proved 99% effective, at an average cost of little more than $1.00 per acre. The timber saved from potential destruction is conservatively valued at $785 per acre.

No doubt, similar methods could prove equally effective in ridding other forests of insects and disease . . . which annually destroy 30% more timber than forest fires. Pennsalt technicians will continue to offer their assistance on these problems from coast to coast.

In the West:
Pennsylvania Salt Manufacturing Company of Washington
Tacoma, Wash. and Portland, Oregon

In the East:
Pennsylvania Salt Manufacturing Company
Philadelphia 7, Pa.

Timber is a crop . . . let's protect it

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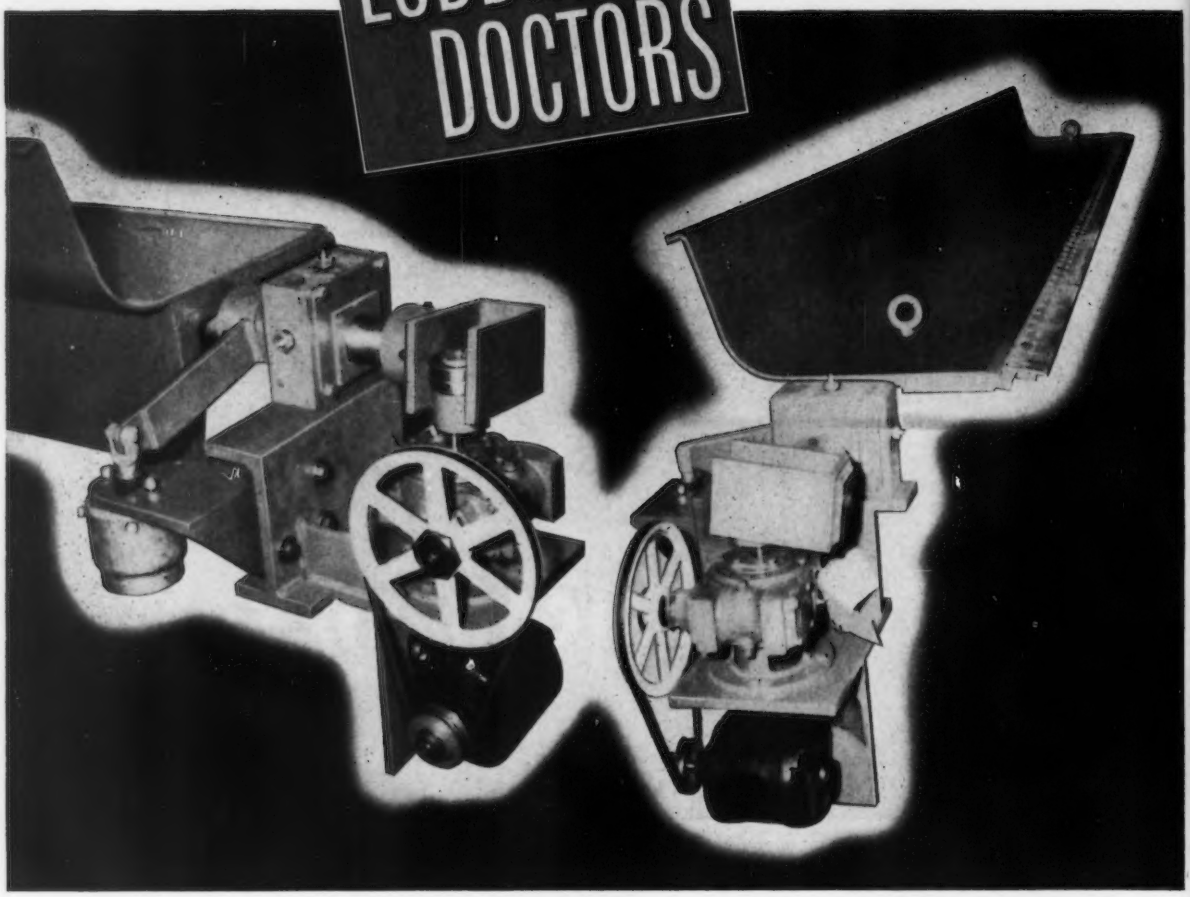
Pennsalt Chemicals

Progressive Chemistry for Over a Century

LODDING DOCTORS



LODDING MODERN OSCILLATING PRESS DOCTOR

with pneumatic throw-off

LODDING ENGINEERING CORPORATION

WORCESTER, MASSACHUSETTS

REPRESENTED BY

W. E. GREENE CORPORATION • WOOLWORTH BLDG., NEW YORK

CLOSE COLLABORATION with our customers results in machines designed for profitable production of paper and for ease of operation. In our engineering conference room, Harry Gochnauer (*left*), Chief Engineer of Northern Paper Mills, checks drawings for a wringer roll installation with Beloit's Chief Engineer Ed. Beachler (*standing*) and Assistant Chief Engineer Burton James.—*Beloit Iron Works, Beloit, Wis.*

WHEN YOU BUY BELOIT... YOU BUY MORE THAN A MACHINE!

BELOIT

PAPER MACHINERY

Your Guarantee of Quality

Look for these seals on all Brown Company Solka and Cellate pulps. They are your guarantee of quality pulp, made from the finest wood cellulose.

Research leadership is one of the main reasons why Brown Company pulps are outstanding. Our laboratories are constantly developing new fibres with special characteristics to enable paper manufacturers to take advantage of the versatile characteristics of wood cellulose. They were the first to make it economical and practical to use hardwood fibres in the manufacture of many products.

Brown Company pulps are made principally from its own vast timberlands of northern softwood and hardwood. This assures quality control and a dependable source of raw material.

If you have a paper problem, however difficult it may be, write to our Technical Service Division. Address Dept. BP-11 in our Boston office.

BROWN QUALITY COMPANY, Berlin, New Hampshire
CORPORATION, La Tuque, Quebec

General Sales Offices: 150 Causeway St., Boston 14, Mass.—Dominion Square Bldg., Montreal, Quebec

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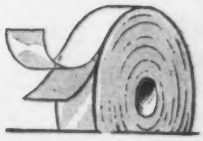
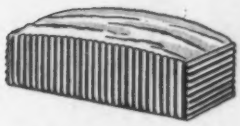
WHEN IT'S RELEASE YOU WANT IN PAPER

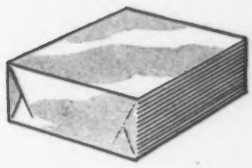
Du Pont "Quilon" is the answer!



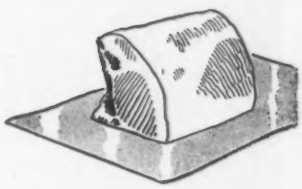
For rubber-separator papers, pressure-sensitive tapes and labels, "Quilon" makes possible easy stripping.



For bakery tray and pan liners, "Quilon" greatly reduces sticking of baked goods.



For frozen-food packages and locker wrap, "Quilon" eliminates fiber pull when frozen-food packages are separated and when frozen food is removed from wrap.



For butcher's wrap and meatboard, "Quilon" reduces sticking, keeps paper from tearing when unwrapped.

When you treat paper with Du Pont "Quilon" stearato chromic chloride, you give it release qualities of unusual functional value. Yet the cost is low because the amount of "Quilon" needed is so small. And the treatment is permanent because "Quilon" is non-migratory—anchors tightly to the fibers of paper.

"Quilon" is water-soluble and easily applied by spray, transfer rolls or immersion. Treatment can be done at the size press or, for heavyweight papers, at calender stack water boxes. "Quilon" doesn't give paper a waxy feel . . . doesn't adversely affect any dry properties of paper.

"Quilon" also provides outstanding water repellency and size

"Quilon" can be used to impart a high degree of size and water repellency to paper. And as a pre-treatment for wax-coated paper, "Quilon" increases lactic-acid resistance. It also has wide application for minimizing undesirable water sensitivity of many soluble coatings and adhesives.

Improved products, greater sales. The novel properties and amazing versatility of Du Pont "Quilon" may help you increase your sales of standard products or make superior new products. Send for the technical bulletin . . . it gives more facts and figures on uses and methods of application.

"Quilon" is a registered trade mark of E. I. du Pont de Nemours & Co. (Inc.)

DU PONT
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150th Anniversary

BETTER THINGS FOR BETTER LIVING
...THROUGH CHEMISTRY

E. I. du Pont de Nemours & Co. (Inc.)
Grasselli Chemicals Department
Wilmington, Delaware

Please send me free technical bulletin describing "Quilon" stearato chromic chloride.

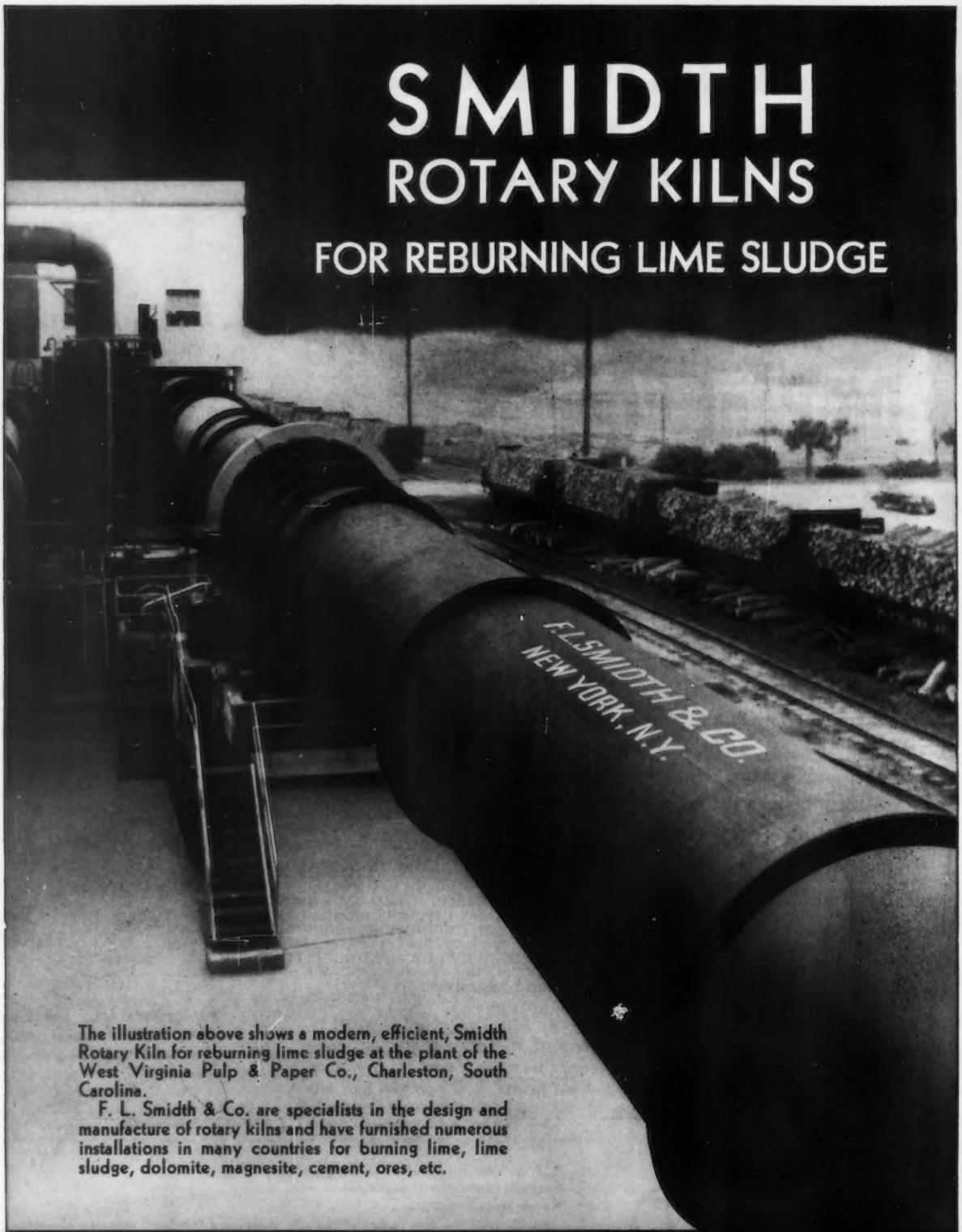
Name_____ Title_____

Firm_____

Address_____

City_____ State_____

SMIDTH
ROTARY KILNS
FOR REBURNING LIME SLUDGE



The illustration above shows a modern, efficient, Smidth Rotary Kiln for reburning lime sludge at the plant of the West Virginia Pulp & Paper Co., Charleston, South Carolina.

F. L. Smidth & Co. are specialists in the design and manufacture of rotary kilns and have furnished numerous installations in many countries for burning lime, lime sludge, dolomite, magnesite, cement, ores, etc.

F. L. SMIDTH & CO.

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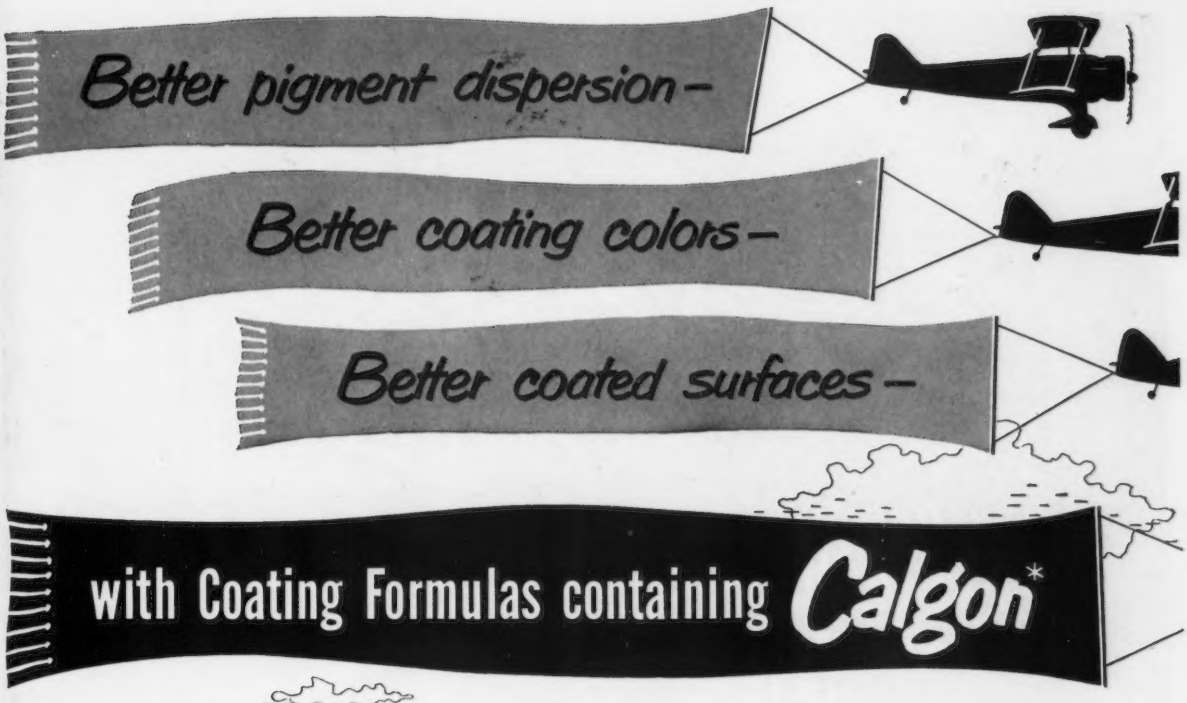
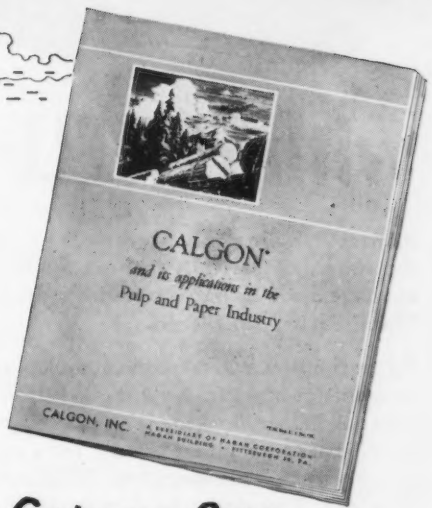


Better pigment dispersion? The superior deflocculating properties of Calgon provide better pigment dispersion, giving a better finished coated stock.

Better coating colors? Calgon improves flow properties of the coating color, and allows the use of higher solids.

Better coated surfaces? Calgon in the coating formula provides a better bond between paper and coating, and results in a smoother surface, free from grit.

The Pulp and Paper Industry utilizes Calgon in many ways. For full information on the advantages and uses of Calgon, get in touch with us today.



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calgon, inc.

A SUBSIDIARY OF HAGAN CORPORATION

HAGAN BUILDING
PITTSBURGH 30, PA.

CALGON, INC.
Hagan Building
Pittsburgh 30, Pa.

Please send me a copy of the booklet, "CALGON and Its Applications in the Pulp & Paper Industry."

Name_____ Title_____

Company_____

Address_____

City_____ State_____

with ELWELL-PARKER Roll Trucks

Anyone handling roll paper will be interested in the substantial savings in time, space, and paper spoilage made by the Youngstown Vindicator with Elwell-Parker Roll Trucks.

By previous manual methods, it took 3 men 4 hours to unload a box car. Now the E-P truck operator, plus one helper, does the job in 2½ hours. Also, the Elwell-Parker double tiers the rolls on the street delivery truck. This operation proved too dangerous manually. Therefore, the number of trips that the street truck must make has been almost cut in half.

In the Vindicator's basement, an Elwell-Parker apron-type roll truck tiers a horizontal row on top of a vertical row, so that 600 tons can be stored. Previous to the purchase of this truck, it was possible to store only 240 tons in this space.

COSTLY SPOILAGE REDUCED—E-P trucks are an important factor in the Vindicator's waste reduction campaign. Their Pressroom Superintendent, Mr. Earl Weiskittel, emphasizes this point with newsprint over $120 per ton . . . For example, any user of 5,000 tons annually who cuts his spoilage with an Elwell-Parker just 1%, will save $6,000 per year. At this rate, an E-P truck can pay for itself in less than a year.

360° CLAMP ROTATION—*In close quarters, the fixed jaw can be positioned on either side.*

GET ALL THE FACTS—

We will gladly send full details on this operation plus our new folder on the Roll Clamp Truck. Write The Elwell-Parker Electric Co., 4193 St. Clair Avenue, Cleveland 3, Ohio.

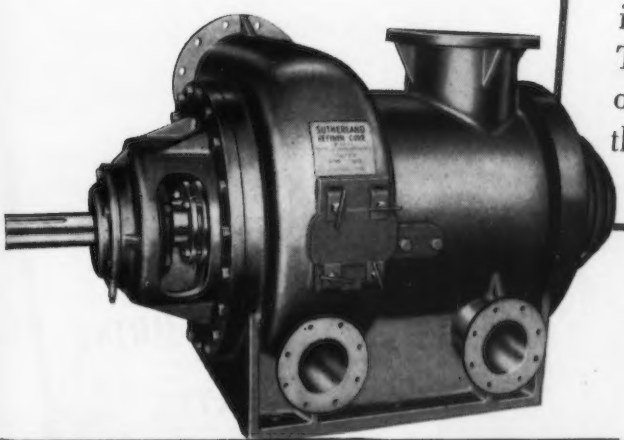
ELWELL-PARKER
POWER INDUSTRIAL TRUCKS
Established 1893

Low Cost

SELECTIVE DEFIBERING

When your brown stock or wash stock passes through a Sutherland Breaker Trap, here's what happens:

First, heavy tramp metal is pulled out quickly by centrifugal force. Then the selective defibering action goes to work and reduces soft, over-size fiber bundles. Hard dirt particles and other forms of waste material are left whole so they can be removed by standard screening methods. Thus the Breaker Trap gives an increased amount of usable fibers, while aiding in the maintenance of a clean sheet.



Because the Breaker trap is designed specifically for this duty, it features rugged construction, high efficiency and low power requirements. Capacities are available for both large and small mills. Write today for illustrated folder.

SUTHERLAND

Patent pending

Breaker Trap

SUTHERLAND REFINER CORPORATION

TRENTON 8, N. J.

Chemicals you live by

ONE CALL *is enough for you*

to order your complete supply of:

SODA ASH
•
CAUSTIC SODA
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LIQUID CHLORINE
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SILICATES
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SALT CAKE

Call DIAMOND for all five basic chemicals—and get prompt delivery. If you have any problems touching the use, handling or storing of any of these chemicals, call DIAMOND. Our technical servicemen are familiar with the paper industry and know the proper use and handling of all of these chemicals.

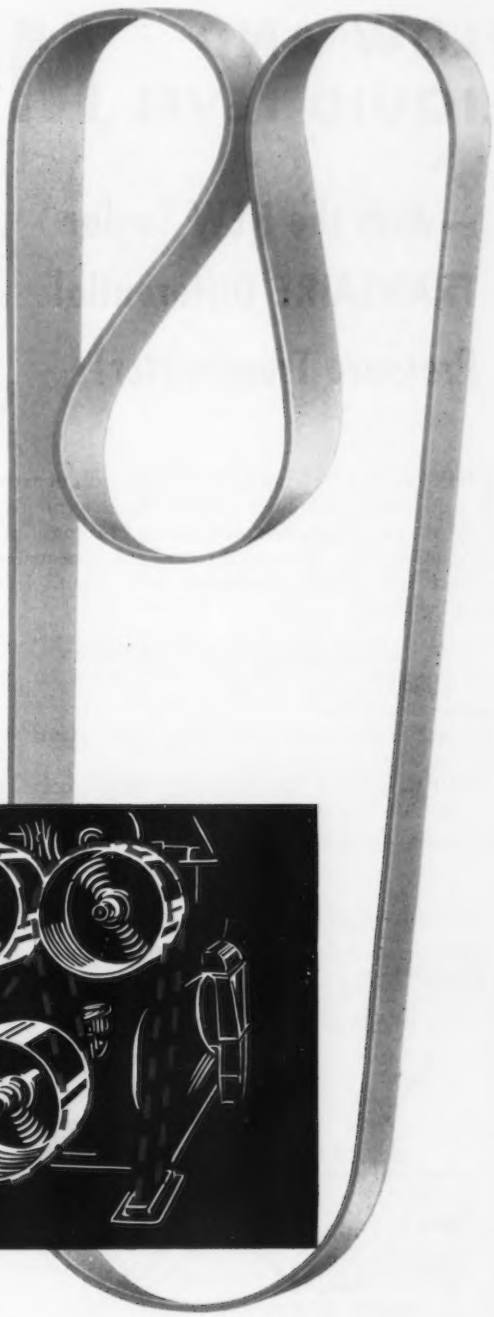
DIAMOND ALKALI COMPANY

CLEVELAND 14, OHIO

DIAMOND ALKALI CHEMICALS ®

your pulleys will drive your machines only as well as your belts drive your pulleys

if you want more production, get GRATON AND KNIGHT leather belting for more production-power

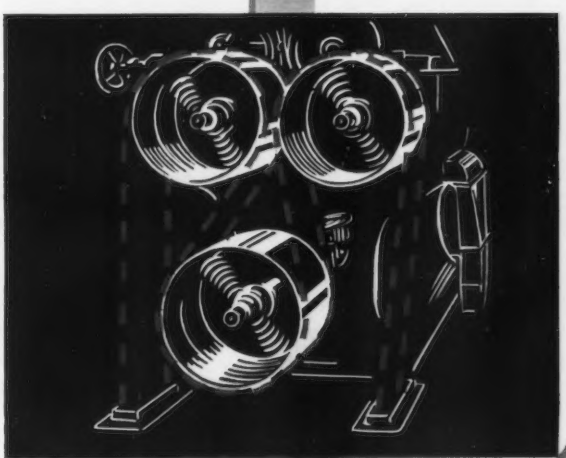


Get a Graton & Knight "Live Traction" Leather Belt — because it is engineered to transmit maximum uniform horsepower at correct speeds and sustained R.P.M. — with ample reserve for load peaks, and "fluid drive action" to absorb starting torque and load shocks.

For tough conditions, cross, shifter and idler drives, **HEART OAK** top grade center stock oak tannage. For short center, small pulley, cone pulley and serpentine *precision* drives, **RESEARCH**® premium quality. For ambient conditions (steam, oil, water, acid and alkali fumes) **SPARTAN**® combination tannage . . . Whatever your conditions, you'll get more production-power with Graton & Knight *Engineered* Leather Belting.

and keep your belts pulling for you
Stop belt slippage — prolong belt life with GRAKO® CLEAR Belt Dressing, result of 100 years experience in leather tanning and belt manufacture. Preserves and lubricates the fibres. Pint, quart and gallon cans—5-gallon and 50-gallon drums. Send for circular.

New Belting Catalog and Manual shows how to get more production-power with leather belting. Our representative will deliver your (free) copy upon request.
GRATON & KNIGHT COMPANY
Worcester 4, Massachusetts

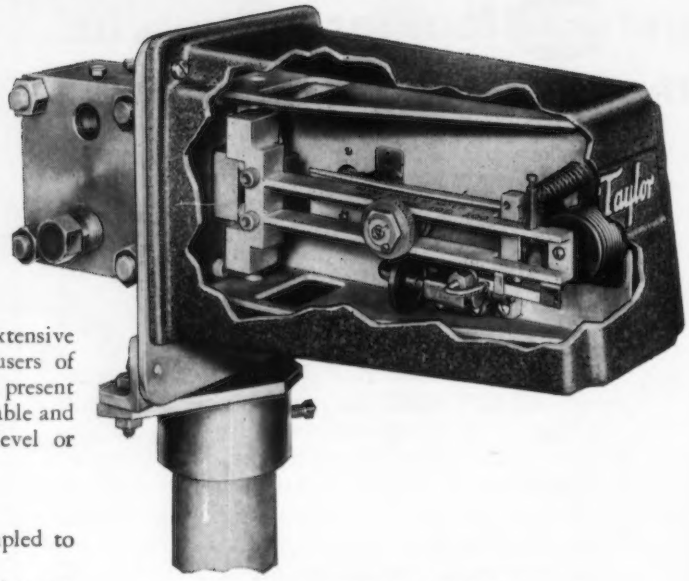


second century G and K **engineered leather belting**
for more production-power

GRATON AND KNIGHT Estab. 1851

Taylor announces SIMPLIFIED FLOW AND LIQUID LEVEL MEASUREMENT

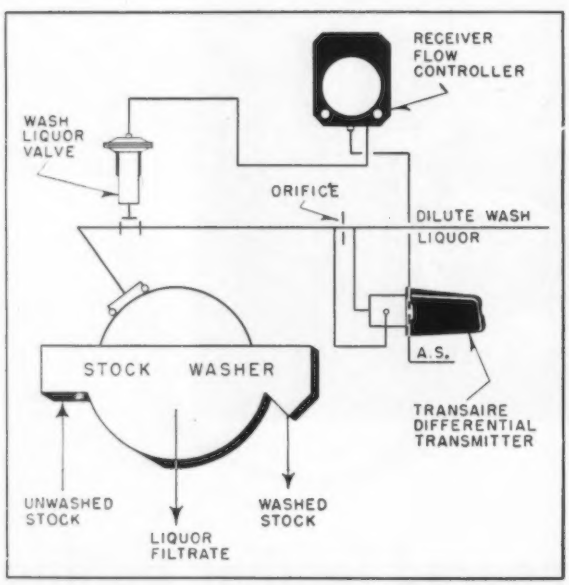
—with the NEW Taylor TRANSAIRE® Differential Pressure Transmitter!



THIS new Taylor Transmitter is the result of extensive field study and close collaboration with users of force-balance transmitters. It is designed to meet present day industrial requirements for a rugged, dependable and accurate instrument to measure flow, liquid level or specific gravity.

Inexpensive, simple installation

- Simplified piping, because it can be close-coupled to orifice flanges.
- No seal pots required, negligible displacement because of force-balance construction.
- Light weight for easy handling; weighs only 23 lbs.



Taylor TRANSAIRE Differential Pressure Transmitter and FULSCOPE Receiver Flow Controller as applied to stock washer.*

*Reg. U. S. Pat. Off.

Easy, economical maintenance

- Self draining or venting—no periodic manual venting or draining.
- Mercuryless; flexible, tough Teflon coated glass fabric diaphragm.
- Overrange protection to full body rating.

Accurate measurement

- Relay valve for linearity, minimum hysteresis, fast speed of response.

Rugged construction, dependable performance

- Weatherproof housing built for tough service and outdoor mounting.
- Force-balance construction; negligible motion, minimum possible wear.

Adaptable

- 100% suppression; continuously adjustable from 0 to 100%. Ideal for liquid level applications.
- Ten-to-one rangeability in each of two forms:
  (a) 20-200″ water; (b) 80-800″ water.

Ask your Taylor Field Engineer for full information about this latest addition to the Taylor family of transmitters, or write for **Bulletin 98226.** Taylor Instrument Companies, Rochester, N. Y., and Toronto, Canada.

Instruments for indicating, recording and controlling temperature, pressure, flow, liquid level, speed, density, load and humidity.

TAYLOR INSTRUMENTS MEAN ACCURACY FIRST

MODEL U7
CLARK-AIKEN GOEBEL SLITTER REWINDER
FOR HIGH SPEED PRODUCTION OF ROLLS
WITH REGULATED HARDNESS.

You're Invited
TO A WEDDING

. . . . . OF SPEED AND PRECISION

The joining of two names, Clark-Aiken and Goebel, long associated with advanced design and quality craftsmanship on two continents, has produced production magic in a new line of slitters and rewinders. If your needs are exacting and production requirements are high, you'll find a happy and economical solution to your problems in this new line.

R. S. V. P. A request from you will bring a practical demonstration of how Clark-Aiken equipment can perform profitably for you in your slitting, rewinding and sheeting operations.

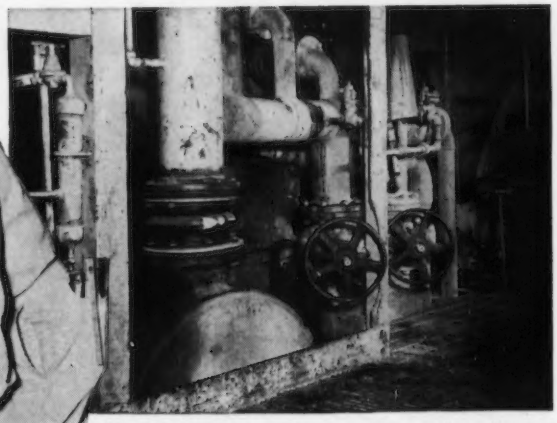
CLARK - AIKEN GOEBEL
MANUFACTURED AND SOLD BY

Clark-Aiken
THE COMPLETE LINE
HIGH SPEED PRECISION
CUTTER-LAYBOY UNITS,
SLITTERS AND REWINDERS

THE CLARK - AIKEN COMPANY
LEE, MASSACHUSETTS

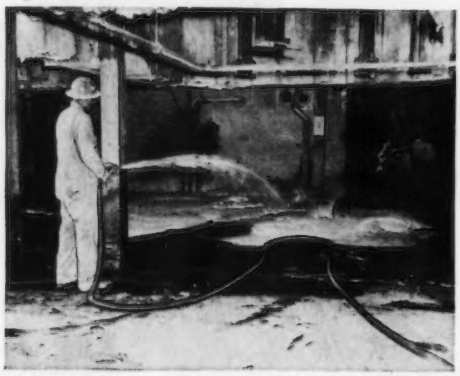
Why is U. S. Rubber a favorite in this mill?

Here is one of a series of six U.S. Rubber Expansion Joints used in one section of this huge mill to protect piping and equipment. Mill superintendents have found U.S. Rubber engineering a big factor in lowering maintenance and replacement costs.

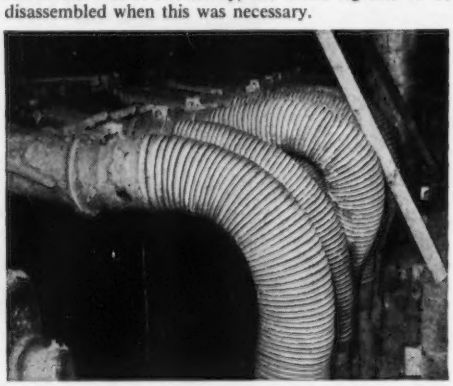


Vibration and expansion, caused by violent chemical reactions in processing chemicals in the pulp mills, are completely absorbed by U.S. Rubber Expansion Joints, thereby preventing weakening and damage to pipe lines.

U. S. Rainbow Water Hose has shown outstanding durability in this service of washing down over-flow from digestors.



A battery of ten pieces of U.S. Multi-Flex permits required flexibility on Paper Machine for easy changing of fourdrinier wires. Previously, the entire rig had to be disassembled when this was necessary.



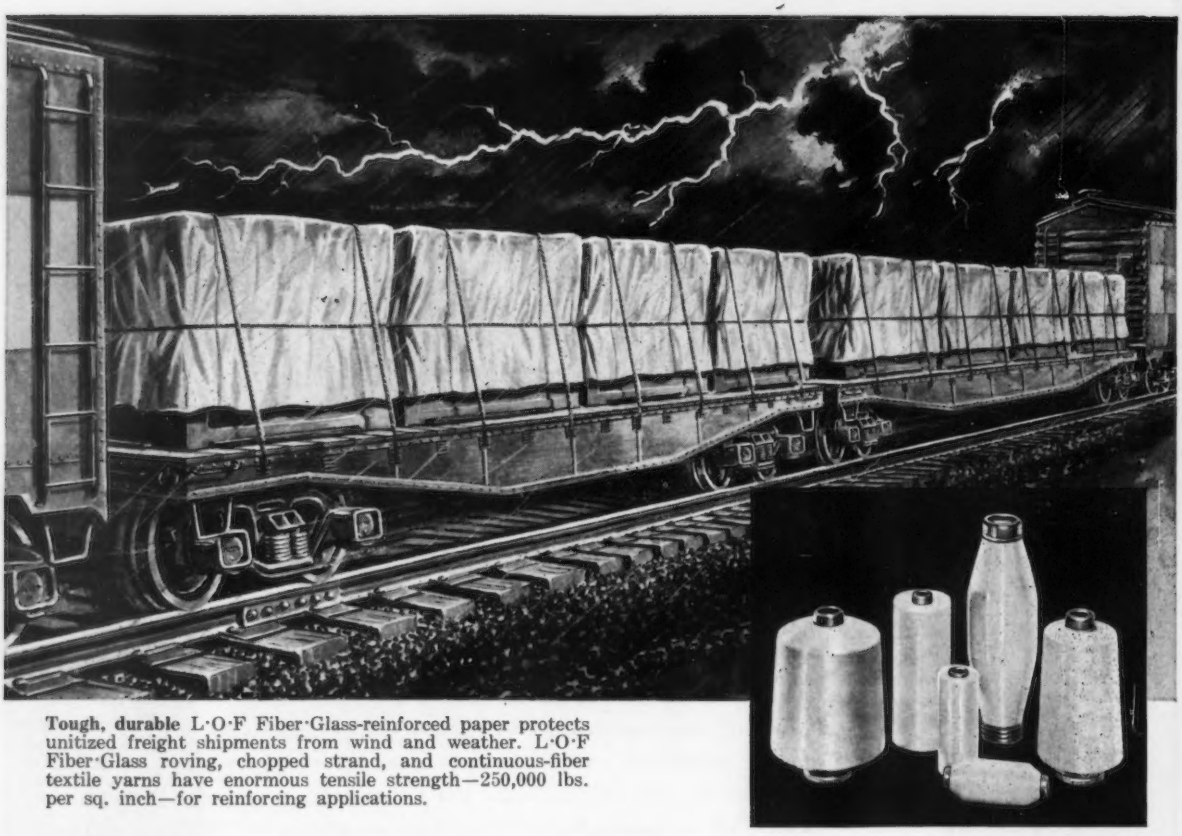
Simply because U.S. Rubber products have *continuously* proved themselves highly economical and satisfactory. Rigid cost accounting in this mill, one of the country's greatest, has established this fact in department after department. Such a statement is of immediate significance to operators of any sized mill, determined on finding ways to keep overhead down. Why not obtain *specific* information by writing us at the address below?

PRODUCTS OF U.S. RUBBER SERVING THROUGH SCIENCE

UNITED STATES RUBBER COMPANY

MECHANICAL GOODS DIVISION · ROCKEFELLER CENTER, NEW YORK 20, N. Y.

for good results—economically
CALCO PHENO BLUES
PHENO BLUE 2B EX. CONC.
PHENO NAVY BLUE
PHENO NAVY BLUE B
PHENO BLUE 7BN EX. CONC.
Possessing the combination of economy, good working properties and satisfactory fastness to light, bleeding and chemicals, the Calco PHENO BLUES are recommended for general use on all types of fiber. They assure uniform results, producing pastel to clear deep shades on tissue, board, wrapping, bag, kraft, and specialty papers.
Why not investigate this group of low-cost blues. Your Calco representative will supply full information on these and other dyes in the extensive Calco line.
Calco
AMERICAN Cyanamid COMPANY
CALCO CHEMICAL DIVISION, DYESTUFF DEPARTMENT
BOUND BROOK, NEW JERSEY
NEW YORK • CHICAGO • BOSTON • PHILADELPHIA • CHARLOTTE • PROVIDENCE
REPRESENTED IN CANADA BY
NORTH AMERICAN CYANAMID LIMITED, CALCO CHEMICAL DIVISION
MONTREAL—TORONTO



Tough, durable L·O·F Fiber·Glass-reinforced paper protects unitized freight shipments from wind and weather. L·O·F Fiber·Glass roving, chopped strand, and continuous-fiber textile yarns have enormous tensile strength—250,000 lbs. per sq. inch—for reinforcing applications.

Wrap up larger markets with glass reinforced paper

L·O·F Fiber·Glass reinforcing makes strong products for countless uses

THERE IS a great potential market for paper reinforced with L·O·F Fiber·Glass. More and more manufacturers have found reinforced paper a new, low-cost protection for wrapping, shipping and storing countless products.

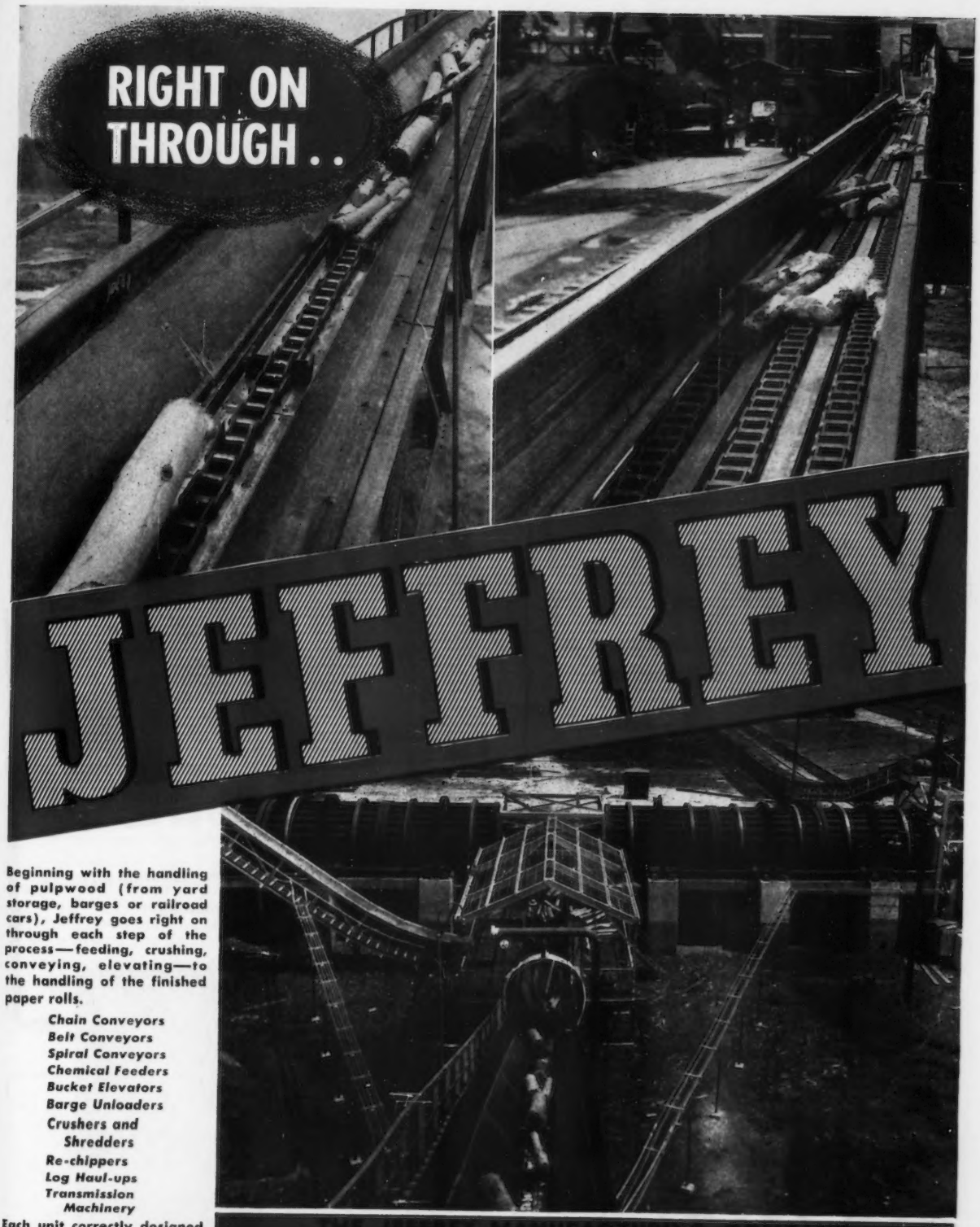
Paper reinforced with L·O·F Fiber·Glass has enormous tensile strength yet remains lightweight and pliable. Strong glass fibers give paper the ability to resist tearing and rupture even when wet. You'll find a ready market for paper strong enough to wrap steel sheets and rugged enough to protect products from the severest weather during shipment or storage.

For more information on the outstanding advantages L·O·F Fiber·Glass can give to your paper or paper tape, contact the nearest L·O·F office (district offices in 25 major cities). Or write, wire or phone Libbey·Owens·Ford, Dept. F.G. 13112, Nicholas Building, Toledo 3, Ohio.

LOF GLASS PLASKON LOF FIBER·GLASS

LIBBEY·OWENS·FORD GLASS COMPANY
FIBER·GLASS DIVISION

FIBER·GLASS



Beginning with the handling of pulpwood (from yard storage, barges or railroad cars), Jeffrey goes right on through each step of the process—feeding, crushing, conveying, elevating—to the handling of the finished paper rolls.

Chain Conveyors
Belt Conveyors
Spiral Conveyors
Chemical Feeders
Bucket Elevators
Barge Unloaders
Crushers and Shredders
Re-chippers
Log Haul-ups
Transmission Machinery

Each unit correctly designed and built to help you modernize by mechanizing . . . to bring your mill up to desired efficiency. Take advantage of our years of experience in serving pulp and paper mills.

THE JEFFREY MANUFACTURING COMPANY
921 North Fourth St., Columbus 16, Ohio

ESTABLISHED 1877

What do you do when you don't have the right size v-belt in stock?

1

Contact your supplier for a replacement

...and wait for delivery
...wait—and watch production stay at zero

2

Send someone to get the required belt

...and pay your employee while he goes for the belt
...pay through loss of production

3

Stock VEELOS...

...and always have the *right* size belt when you need it
...any length can be made up from a 100-foot reel
...inventory is automatically maintained
...available from 350 distributors

GET ALL THE FACTS

This Veelos Data Book gives complete details about construction, installation and uses. Write for free copy of this money-saving book today.

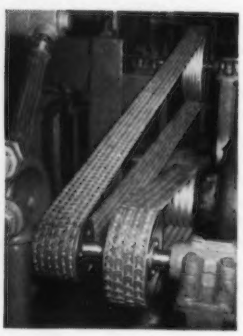
MANHEIM MANUFACTURING & BELTING COMPANY
616 Manbel St., Manheim, Pa.

VEELOS in stock is Production Insurance

Belts for replacement always on hand—just 4 reels of Veelos in the O, A, B and C widths can replace up to 316 different sizes of endless v-belts.

Link construction permits quick installation—without removing outboard bearings.

Adjustability provides controlled tension on each belt—vibrationless, full power delivery is assured.



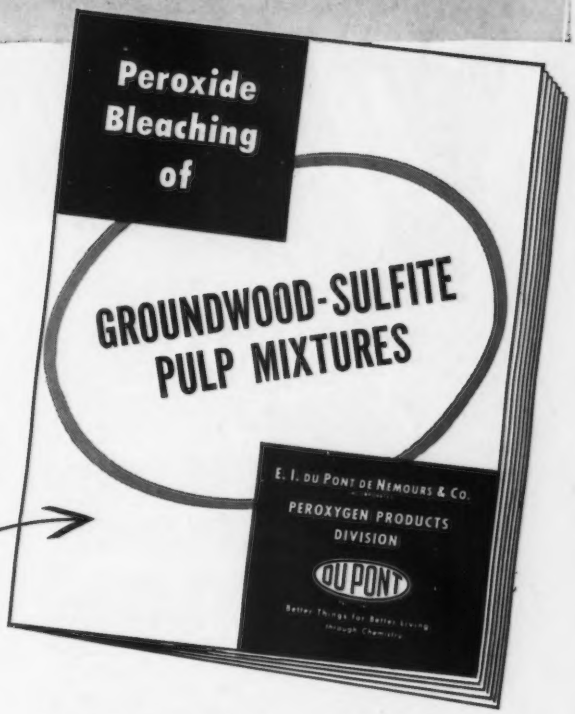
VEELOS
THE LINK
V-BELT

ADJUSTABLE TO ANY LENGTH · ADAPTABLE TO ANY DRIVE

Made in all widths in three types: regular, oil-proof, static conducting. Also double V in O, A and B. Packaged on reels in 100-foot lengths. Sales engineers in principal cities; over 350 distributors throughout the country. VEELOS is known as VEELINK outside the United States.

How to produce premium grades of printing paper at low cost

Upgrade both groundwood and sulfite pulps in one peroxide bleaching operation



Peroxide bleaching of groundwood-sulfite mixtures enables mills to process the entire paper furnish in one bleaching operation . . . reduces capital investment for bleaching equipment and lowers operating costs. Bleached pulps produced with this process feature superior brightness, cleanliness, absorbency and paper machine formation characteristics . . . are ideally suited to the economical production of premium grade printing papers.

COMPLETE INFORMATION on peroxide bleaching of groundwood-sulfite mixtures is available from Du Pont. The coupon below will bring you a new Du Pont book describing the process in detail: economies, equipment used, raw materials required, preparing the bleaching solution, steps in the bleaching operation and chemical control tests. Send for your copy today. You'll find it a valuable source of information for all types of pulp bleaching. E. I. du Pont de Nemours & Co. (Inc.), Electrochemicals Dept., Wilmington 98, Delaware.

SEND FOR THIS NEW DU PONT BOOK TODAY!

DU PONT
PEROXIDES
FOR GROUNDWOOD BLEACHING

IN DRUMS AND TANK CARS
"Albone" 35 . . . . . Hydrogen Peroxide, 35%
"Albone" 50 . . . . . Hydrogen Peroxide, 50%
"Solozone" . . . . . Sodium Peroxide

DUPONT
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150th Anniversary
BETTER THINGS FOR BETTER LIVING . . . *THROUGH CHEMISTRY*

E. I. du Pont de Nemours & Co. (Inc.)
Electrochemicals Dept., Wilmington 98, Delaware

Please send me my copy of "Peroxide Bleaching of Groundwood-Sulfite Pulp Mixtures."

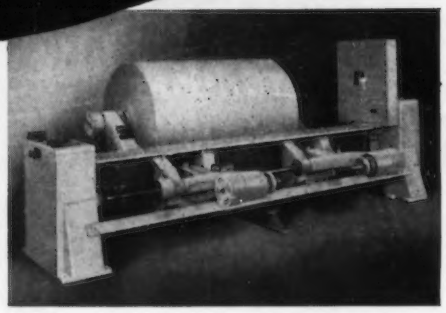
*Name*_____ *Position*_____

*Firm*_____

*Address*_____

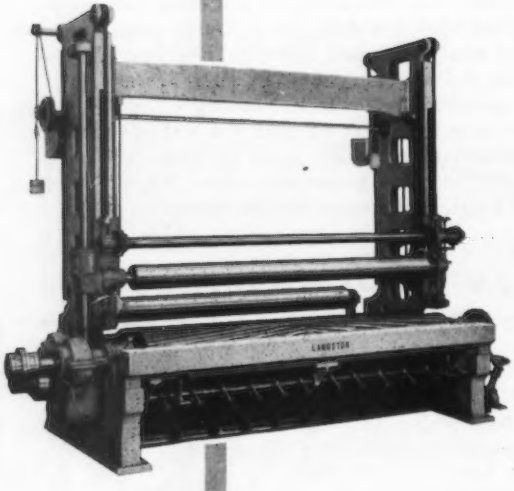
*City*_____ *State*_____

LANGSTON SHAFTLESS *Mill Roll Stands*



Various types of Langston Mill Roll Stands are available, equipped with constant tensioning, side register control, etc. Special construction can be provided to receive customers' reels or unwinding shafts. Shaftless type, self loading Langston Mill Roll Stands also are available.

SAMUEL M. LANGSTON CO.
Camden, N. J.



Langston SLITTERS and WINDERS

TISSUE
SANDPAPER
CHECK PAPER
CREPE PAPER
CIGARETTE PAPER
CARTONS
CARDBOARD
Lindsay
Fourdrinier wires
helps to make
good paper products
better
THE LINDSAY WIRE WEAVING COMPANY
CLEVELAND 10, OHIO
Lindsay WIRES
FOR PAPER MILLS
Sold with Service
100 LBS.
STRONG·UNIFORM
DEPENDABLE
PAPER
BAGS
WADDING
BOOK PAPER
WALL BOARD
WALL PAPER

8 Sandy Hill Packer Superscreens®

start their journey to Pryor, Oklahoma and the New Board Mill of the

National Gypsum Co.

Sandy Hill Packers Offer Choice of 3 Types of Drives

Packer Superscreen Model LH*

This model has a totally enclosed, noiseless roller shoe unit with continuous lubricating system. No oil leakage.

Packer Superscreen Model F

Electric steel casting roller shoes and steel forging cams require less horsepower, lessen vibration and noise, and lower maintenance cost. Replacing wooden blocks is eliminated.

Packer Superscreen Model T

The original Packer design with hardwood or composition toe blocks for the lowest cost installation.

*National Gypsum Specified Model LH

PACKERS were specified for National Gypsum's $5,000,000 push-button board paper mill because its operators wanted ***"the best pulp screen the trade had to offer".***

Mill men repeatedly specify Packers because their experience has proved that Packers:

- **Produce higher tonnage of cleaner pulp per plate.**
- **Offer a more reliable medium for grading and carding fiber bearing stock on either board machine or fourdrinier.**
- **Require less maintenance and care.**
- **Have sturdy construction for long trouble-free life.**

Mechanical improvements and modifications of the past ten years have increased the efficiency, capacity, adaptability and service life and greatly simplified operation and maintenance while still adhering to William Packer's screening principles.

Sandy Hill's new Brochure of Pulp and Paper Making Machinery is available on request.

The Sandy Hill Iron & Brass Works

Hudson Falls, N.Y.

Machinists and Founders Specializing in Paper and Pulp Mill Machinery

Manufacturers of
Adjustable Cylinder Vats
Cylinder Paper Machines
Kamyr Pulp Grinders
Dandy Roll Drives

Quick Opening Gate Valves
Bertrams Flow Distributors
Bertrams Shakes
Kamyr Stock & Pulp Pumps
Kamyr Vacuum Washers

Neilson Slice
Kamyr Feltless Wet Machines
Selective and Corner Drives
Fourdrinier Paper Machines
Packer Screens

Castings
Kamyr Pulp Bleaching Equipment
Scofield Felt Conditioners
Yankee Fourdrinier Machines
Yankee Cylinder Machines

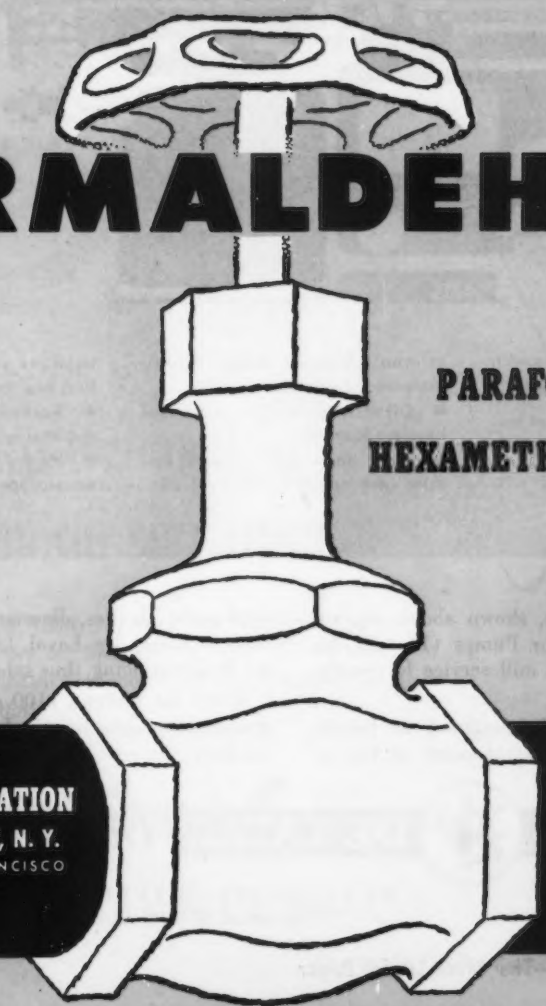
By simply opening a valve, you can put Heyden Formaldehyde to work in your process. Your pumps and pipe lines will deliver from your storage tanks a reliable raw material which will assure top quality in your finished product.

With Heyden Formaldehyde in your tanks, you have the advantage of these important features:

- **Highest purity.**
- **Constant uniformity and assay.**
- **Ease and economy of handling.**
- **Dependable source of supply.**
- **Availability as Formaldehyde Solution N.F. and 37% Methanol-free Formaldehyde.**
- **Shipment in tank cars, tank trucks, 475 lb. drums, 100 lb. carboys and 1, 5 and 9-lb. bottles.**

At the turn of a valve...

HEYDEN FORMALDEHYDE



PARAFORMALDEHYDE

HEXAMETHYLENETETRAMINE

FINE HEYDEN CHEMICALS

HEYDEN CHEMICAL CORPORATION

342 Madison Ave. • New York 17, N. Y.

CHICAGO • PHILADELPHIA • SAN FRANCISCO
DETROIT • PROVIDENCE

BENZALDEHYDE • BENZOATES • BENZYL CHLORIDE
BROMIDES • CHLORINATED AROMATICS • CREOSOTES
FORMALDEHYDE • FORMIC ACID • GLYCEROPHOSPHATES
GUAIACOLS • HEXAMETHYLENETETRAMINE
MEDICINAL COLLOIDS • METHYLENE DISALICYLIC ACID
NEOMYCIN • PARAFORMALDEHYDE
PARAHYDROXYBENZOATES • PENICILLIN
PENTAERYTHRITOLS • PROPYL GALLATE • RESORCINOL
SALICYLATES • SALICYLIC ACID • STREPTOMYCIN

DE LAVAL
LIQUOR PUMPS

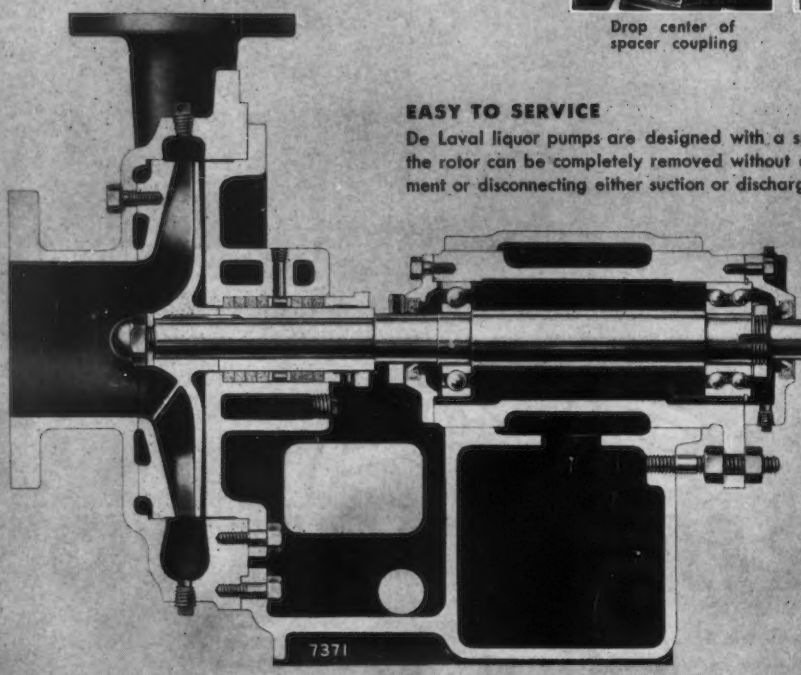
for tough recovery mill service

Drop center of spacer coupling

Pull rotor back and lift out

EASY TO SERVICE

De Laval liquor pumps are designed with a spacer coupling so that the rotor can be completely removed without disturbing motor alignment or disconnecting either suction or discharge piping.



SIZES 3" to 6"

CAPACITIES 100 gpm to 2,500 gpm

HEADS 20' to 150'

SPEEDS 1,150 rpm for most services requiring continuous operation

- One piece suction nozzle with single joint minimizes leakage.
- Eductor vanes on back of impeller relieve stuffing box pressure.
- Rotor can be adjusted with external adjusting screw to compensate for wear.
- Oil mist lubrication minimizes bearing friction.
- Extra deep stuffing box has inlet and outlet water seal connections and inlet and outlet stuffing box cooling connections.
- Suction liner is easily and inexpensively renewed.
- Heavy stiff shaft withstands severe operating conditions.

The important design features, shown above, explain why De Laval type CL Liquor Pumps (1) take the punishment of tough recovery mill service for years; (2) cut maintenance costs.

These pumps are especially designed to handle "tough" *corrosive* or *erosive* liquids such as hot or cold acids, alkalies, digester liquors, milk of lime, etc. What's more, De Laval Liquor Pumps are easy to get at for servicing, thus substantially reduce downtime.

Write for Bulletin 1100 giving full application and specification data on De Laval pumps for the paper industry.

DE LAVAL *Liquor Pumps*

DE LAVAL STEAM TURBINE COMPANY
Nottingham Way, Trenton 2, New Jersey

DL142

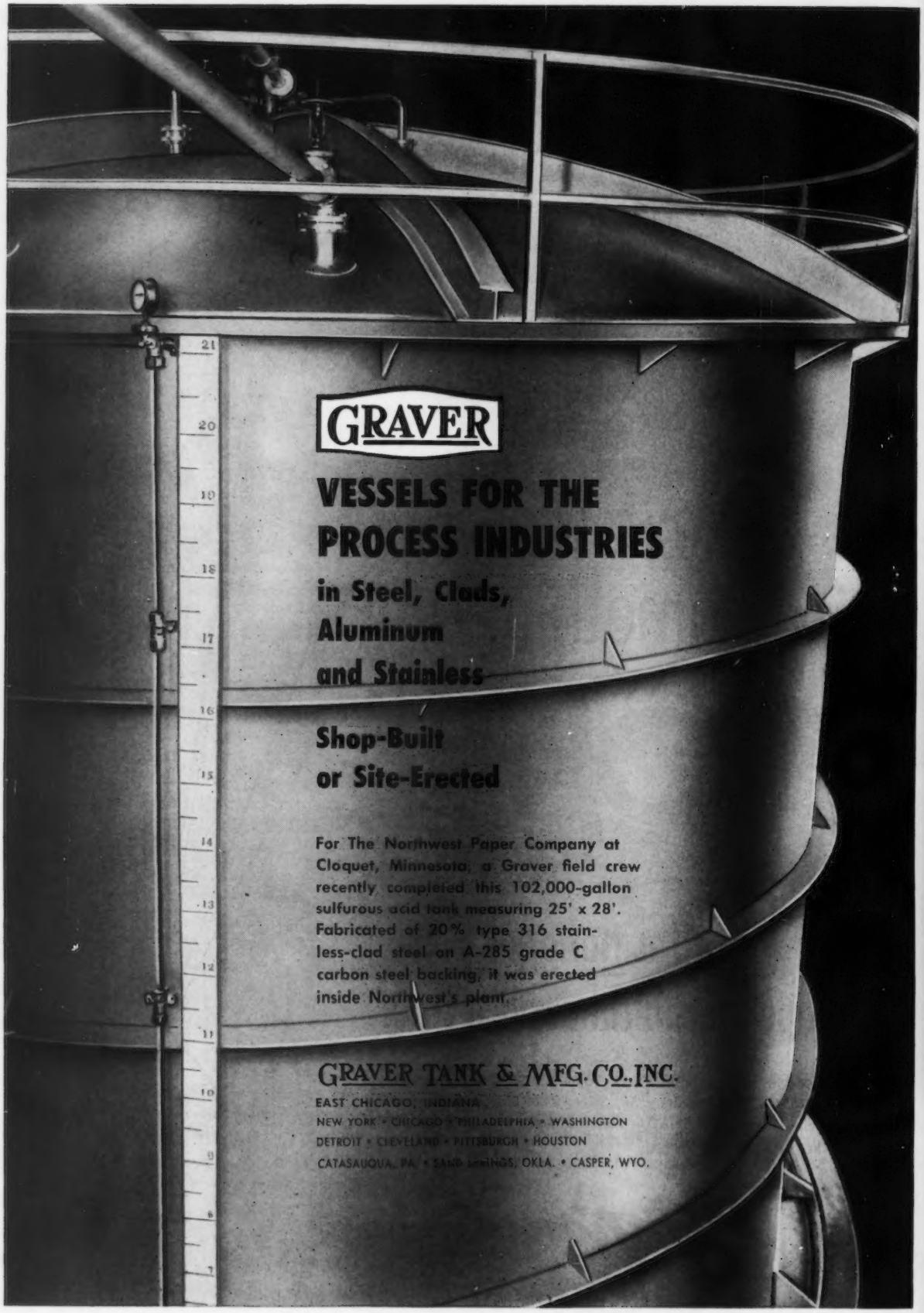
Next time something POPS

call a National paper technical service man

270 Madison Ave., NEW YORK 16; 3641 So. Washtenaw Ave., CHICAGO 32; 735 Battery St., SAN FRANCISCO 11; and other principal cities. In CANADA: National Adhesives (Canada) Ltd., TORONTO and MONTREAL.

STARCHES **National** ADHESIVES

NATIONAL STARCH PRODUCTS INC.


GRAVER
VESSELS FOR THE PROCESS INDUSTRIES
in Steel, Clads, Aluminum and Stainless
Shop-Built or Site-Erected
For The Northwest Paper Company at Cloquet, Minnesota, a Graver field crew recently completed this 102,000-gallon sulfurous acid tank measuring 25' x 28'. Fabricated of 20% type 316 stainless-clad steel on A-285 grade C carbon steel backing, it was erected inside Northwest's plant.
GRAVER TANK & MFG. CO., INC.
EAST CHICAGO, INDIANA
NEW YORK • CHICAGO • PHILADELPHIA • WASHINGTON
DETROIT • CLEVELAND • PITTSBURGH • HOUSTON
CATASAUQUA, PA. • SAND SPRINGS, OKLA. • CASPER, WYO.

VACUUM PICK-UP ARRANGEMENTS

Engineered to meet your needs...

Following the first installation several years ago on a machine manufacturing light and medium weight Kraft papers, the use of the so-called "vacuum pick-up and transfer" has grown by leaps and bounds until today many installations have been made and many more are under construction for operation on newsprint, waxing, and other grades.

The automatic handling of the sheet from the wire to the press felt, instead of the conventional handling methods, permits safe machine operation at considerably higher speeds with a resulting increased production.

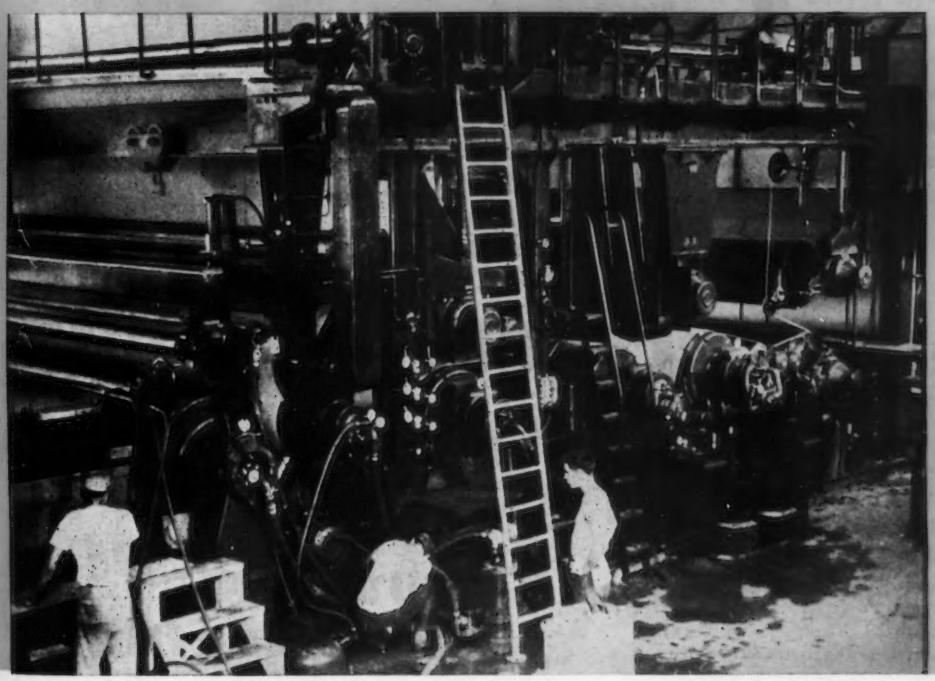
In the case of newsprint, the quantity of chemical pulp content may be reduced substantially.

Puseyjones have built and supplied this arrangement for two new machines and have one under construction for an existing machine.

As with all new ideas, refinements and changes have been made since the original installation. As a result, several arrangements may be used depending upon space limitations, product requirements and other considerations.

Whether you are interested in this equipment for a new machine or modernizing present equipment, Puseyjones engineers are at your service.

THE PUSEY AND JONES CORPORATION
Established 1848. Builders of Paper-Making Machinery
Fabricators and Welders of all classes of Steel and Alloy Products.
Wilmington 99, Delaware, U. S. A.



Illustrated at left is actual installation of Vacuum Pick-Up Arrangement on 236" Machine.

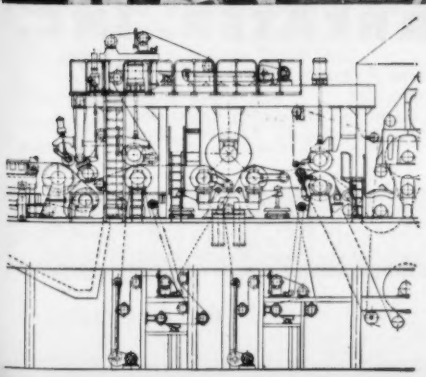
Line drawings (left to right) show:

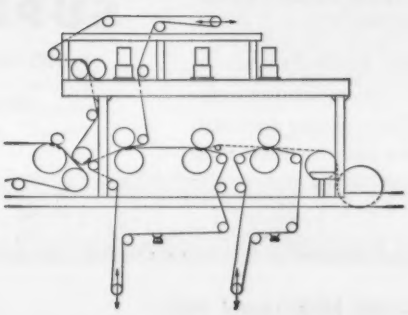
Original arrangement with Transfer Press and combination 3-Roll Main Presses (Cloverleaf).

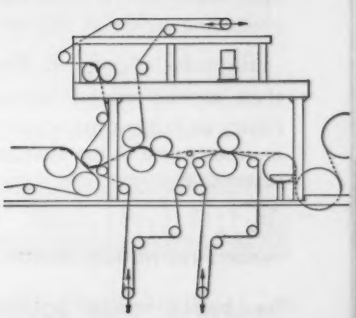
Modified arrangement with Transfer Press and conventional Main Presses.

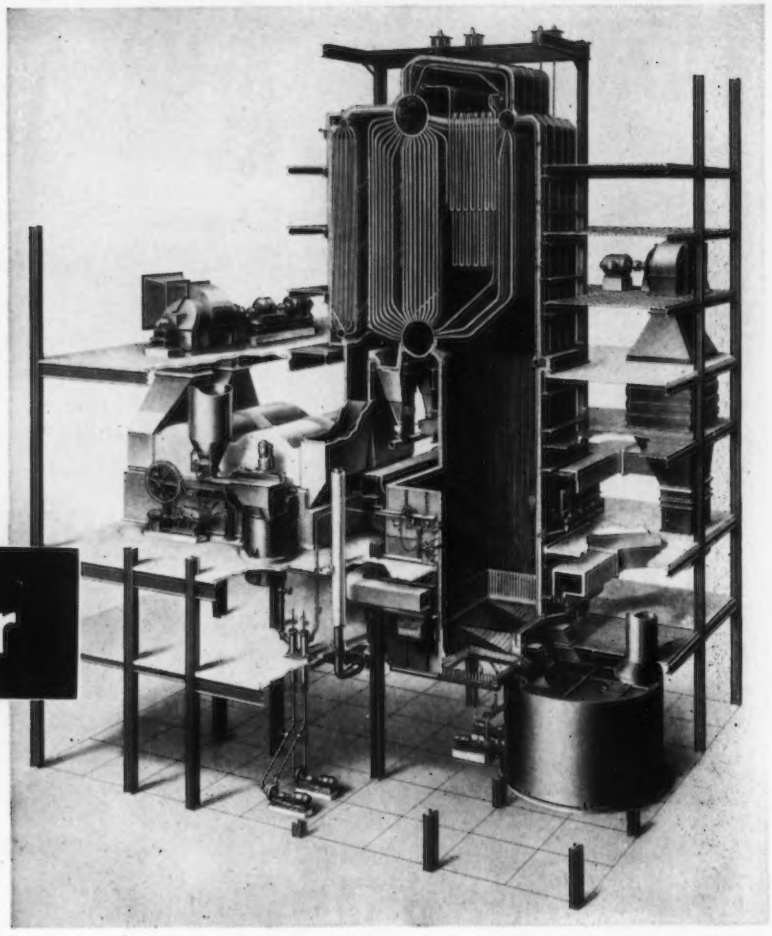
Modified arrangement with combination Transfer and Main Press (Multipress) and conventional Second Press. Minimum space required.

THE SIGN OF TRADE MARK SUPERIOR QUALITY









Rayonier selects C-E recovery units

Designed for the production of chemical cellulose, the new mill of Rayonier, Inc., located at Jesup, Ga., is the focal point of its multimillion dollar expansion program. When completed in 1954, this streamlined plant will up Rayonier's annual production of cellulose by 87,000 tons.

Two C-E Recovery Units will be installed in this mill. Each unit is designed to burn black liquor—producing steam at 625 psi and 760 F.

Rayonier chose C-E Recovery Units because of their service-proved reputation for reliability, efficiency and operating economy. Their choice adds still another name to the ever growing list of leaders who select C-E.

COMBUSTION ENGINEERING—SUPERHEATER, INC.

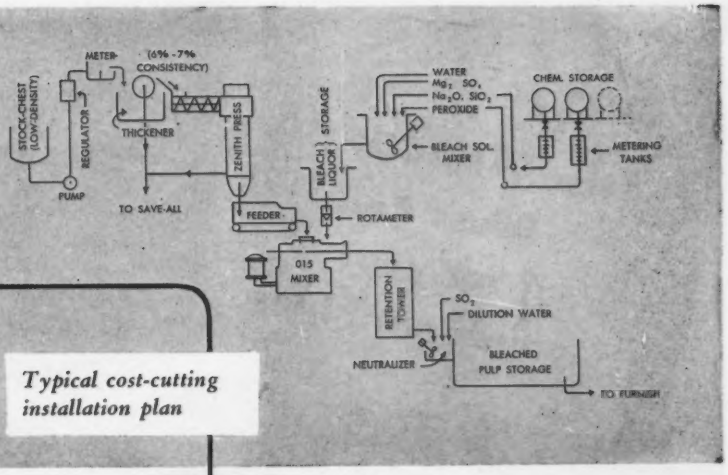
200 Madison Avenue • New York 16, N. Y.

Canada: Combustion Engineering Corporation, Ltd.
Montreal, Toronto, Vancouver, Winnipeg

B-622

PRODUCTS FOR THE PAPER INDUSTRY INCLUDE RECOVERY UNITS, STEAM GENERATING, FUEL BURNING AND RELATED EQUIPMENT; ALSO PRESSURE VESSELS

Jackson and Church — HIGH DENSITY SYSTEM



Typical cost-cutting installation plan

INCREASE BRIGHTNESS... DECREASE COSTS!

Recently, exhaustive tests using the J-C High Density System were conducted under actual mill conditions. These tests proved conclusively that the J-C System saves 12.8 pounds of bleach per ton of groundwood pulp. *For a 150 ton plant this means a saving of 1920 pounds of bleach in one day's operation!* Benefits from high density bleaching of sulphite pulp are even greater.

A TYPICAL RECORD OF THE SAVINGS REALIZED FROM THE J-C HIGH DENSITY SYSTEM

From the graph it will be found that at 5% consistency the points brightness increase per point of peroxide is 0.265; and at 40% consistency it is 0.393.

For ten points brightness increase, there will be required, per ton of pulp

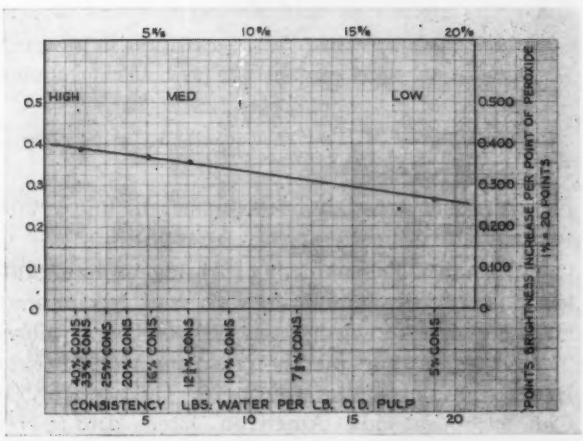
@ 5% — $\frac{10}{.265}$ = 38.7 lbs. H_2O_2 per ton

@ 40% — $\frac{10}{.393}$ = 25.4 lbs. H_2O_2 per ton

Saving = 13.3 lbs. H_2O_2 per ton of pulp

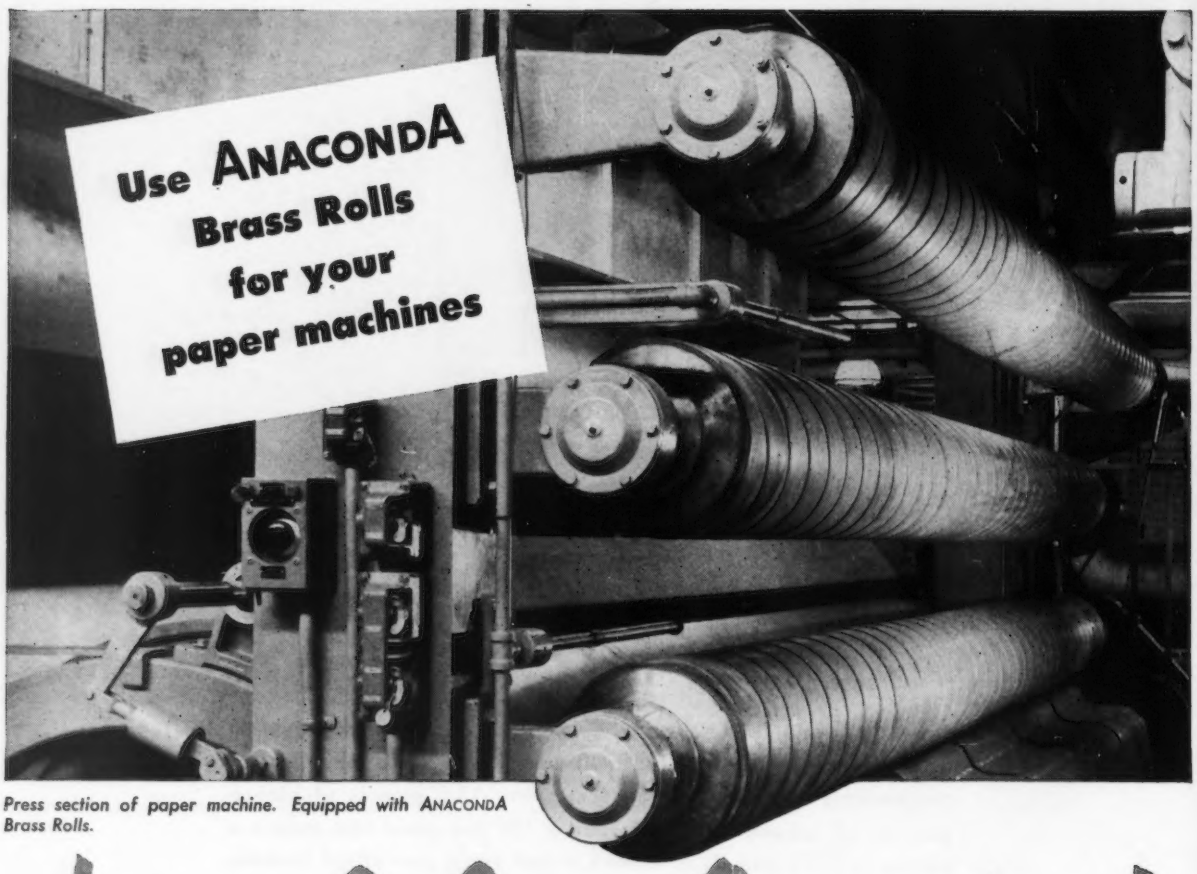
Thus for a production of 150 tons per day, assuming 350 working days in the year and a cost of 28½c per lb. for H_2O_2: (Saving) 13.3 x $0.285 x 150 x 350 = $200,000.

The J-C Zenith Press and J-C Mixer are especially designed for use in handling the high consistencies possible with the Jackson & Church High Density System.



Our engineering department is available for cost analysis.

JACKSON & CHURCH COMPANY · SAGINAW, MICHIGAN



Press section of paper machine. Equipped with ANACONDA Brass Rolls.

be safe from Corrosion!

BRASS is the economy metal for corrosion resistance —the metal that does the job at lowest cost.

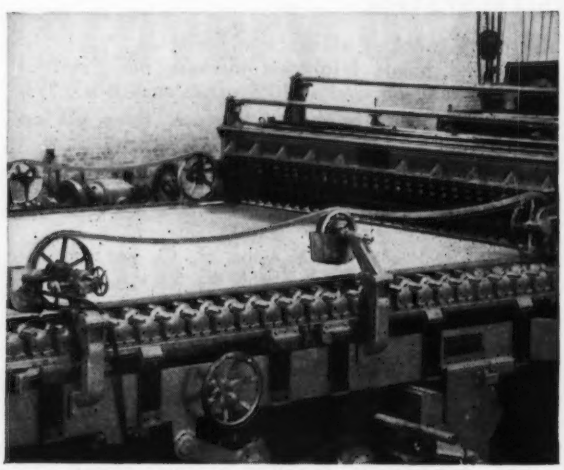
For the resistance of brass to corrosion is inherent. Brass rolls need no protection, no covering against attack by water or chemicals.

You can also count on brass rolls to stay clean—there's no tendency to pick up stock.

For rolls that are right in composition, fabrication, tolerances and finish—specify ANACONDA.

Our Technical Department can bring to your problem both its long familiarity with your special needs and its expert knowledge and skills in copper alloys. This service is yours merely by writing The American Brass Company, Waterbury 20, Connecticut. In Canada: Anaconda American Brass Ltd., New Toronto, Ontario.

50181



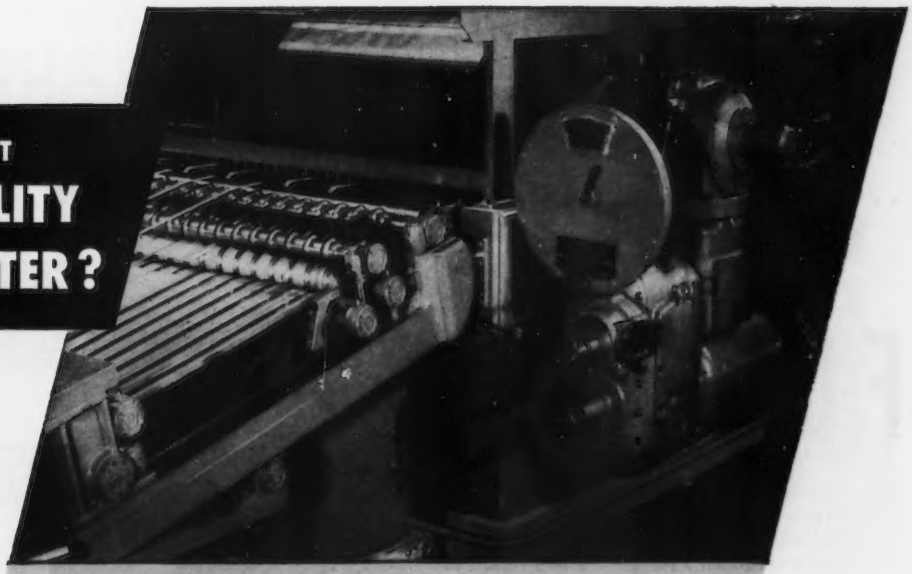
Fourdrinier section of paper machine with ANACONDA Brass Rolls.

PHOTOS COURTESY: RICE BARTON CORPORATION

For dependable paper production... use ANACONDA® BRASS ROLLS

DO YOU WANT

VERSATILITY IN A CUTTER?



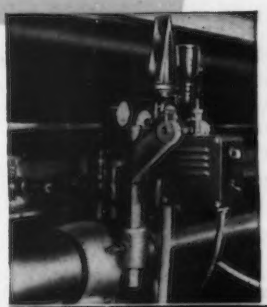
INVESTIGATE THE

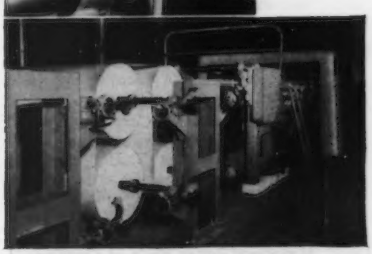
NEW DOWNINGTOWN

MASSON-SCOTT SUPER CUTTER & LAYBOY

Versatility in a cutter and layboy means that it can handle sheet size changes and stacking automatically with but few simple adjustments by the operating personnel. This type of versatility is available in the new Downingtown Masson-Scott Cutter and Overlapping Layboy. It is precision engineered for high speed cutting accuracy and is easily adjustable to meet special production problems.

Your Downingtown Sales Engineer will submit complete data about the Downingtown Masson-Scott Super Cutter and Layboy or write for Bulletin No. 252A.





(Above) automatic counter installed on a Downingtown Masson-Scott Super Cutter. (Below) Backstands with tension and positioning devices.

MODERNIZATION IS CONSERVATION

DOWNINGTOWN MANUFACTURING COMPANY, DOWNINGTOWN, PA.

Pacific Coast Representative: John V. Roslund, Pacific Building, Portland 4, Oregon

Downingtown Fibrepulper, Manufactured in Canada by Waterous, Limited, Brantford, Ontario

DOWNINGTOWN

MASSON-SCOTT SUPER CUTTER & LAYBOY

DESIGNERS AND BUILDERS OF PAPER, BOARD AND FELT MACHINES SINCE 1880

You could hardly find a pulp or paper mill...

...for which instrumentation was not engineered at

FOXBORO

Process control instrumentation for nearly every leading pulp and paper mill in the United States and Canada has been *engineered at Foxboro*. The reason is simple. Foxboro engineering is based on acknowledged leadership — in knowledge of the industry's requirements, in research, in application experience, in product design and diversity.

In the labs and on the drawing boards at Foxboro, today, are tomorrow's developments for pulp and paper processes . . . developments that will carry on the Foxboro *tradition* of originating the instrument systems that boost production and increase quality and uniformity throughout the industry.

The Foxboro Company,
2311 Norfolk St.,
Foxboro, Mass., U.S.A.

In the plans for nearly every modern mill, many hours of creative engineering work like this . . . AT FOXBORO . . . have played a vital part.

Leading mills know that extensive use of advanced instrumentation leads to operating efficiencies never before possible. Significantly, of the industry's newest mills, an overwhelming majority selected Foxboro to engineer and supply mill-wide instrumentation. Typical examples include:

*Rayonier, Inc., Doctortown, Ga.
*Buckeye Cellulose Corp., Perry, Fla.
Riegel Carolina Corp., Acme, N. C.
Brown Co., Berlin, N. H.
Southern Paperboard Corp., Port Wenthworth, Ga.
Macon Kraft Company, Macon, Ga.
Weyerhaeuser, Pulp Div., Longview, Wash.
Weyerhaeuser, Pulp Div., Springfield, Ore.
Marathon Paper Mills of Canada, Ltd., Marathon, Ont.
Long Lac Pulp & Paper Co., Ltd., Terrace Bay, Ont.
Columbia Cellulose Co., Ltd., Watson Island, B. C.
Sorg Pulp Co., Ltd., Port Mellon, B. C.
St. Lawrence Corp., Ltd., Red Rock, Ont.
Fraser Companies, Ltd., Newcastle, N. B.
MacMillan & Bloedel, Ltd.,
Harmac Div., Nanaimo, B. C.

**Under construction*

FOXBORO
REG. U. S. PAT. OFF.

Pulp and Paper Mill INSTRUMENTATION

FACTORIES IN THE UNITED STATES, CANADA AND ENGLAND

THIS MORDEN COMBINATION

Saves SPACE • POWER
LABOR • MAINTENANCE

SLUSH-MAKER
STOCK-MAKER

Simplicity keynotes the Morden systems of stock preparation. Experience shows that these systems give outstanding results in terms of efficiency and economy for quality control. A simple basic system is shown in the flow diagram, using...

MORDEN "SLUSH-MAKERS" for completely pulping, deflaking, mixing and pretreating the furnish.

MORDEN "STOCK-MAKERS" for continuously beating and refining the stock ahead of the paper machine.

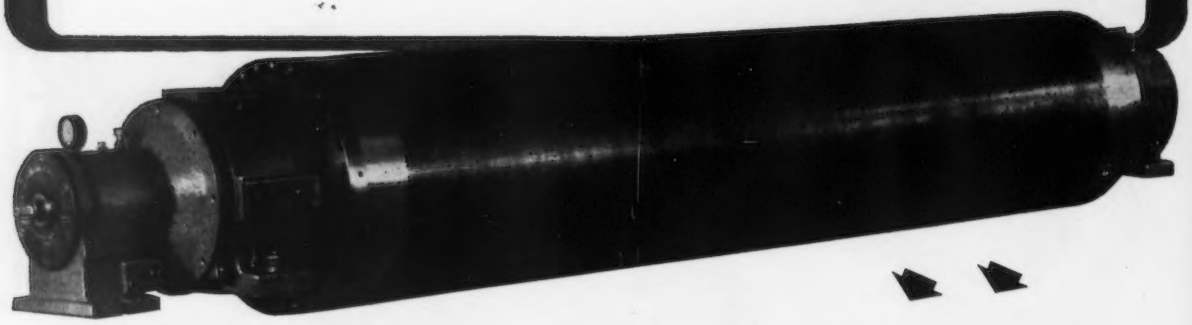
Many adaptations and elaborations of this system are used to suit various mill requirements. May we help you simplify and improve your preparation system with Mordens? Let us know your requirements.

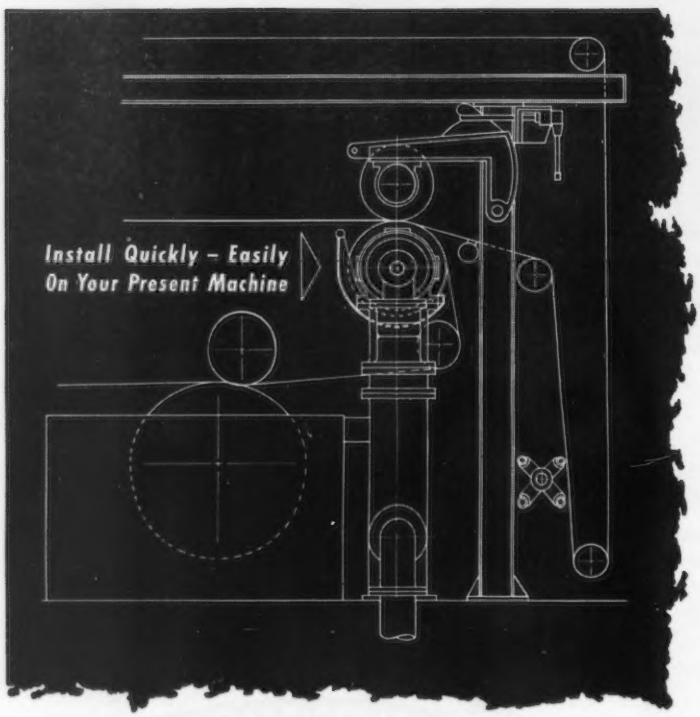
SLUSH-MAKER
MORDEN
Machines Company
STOCK-MAKER

CORBETT BUILDING
PORTLAND 4, OREGON

YOU'LL SAY SO, TOO — WHEN YOU INSTALL

A MANCHESTER SUCTION DRUM ROLL





Schematic drawing of an actual application of a Manchester Suction Drum Roll on a board machine. Note how simple and economical it is to install.

IMPROVES PAPER QUALITY
STEPS UP PROFITS
CUTS COSTS · 7 PROVED WAYS

HERE'S WHAT YOU GET . . . .

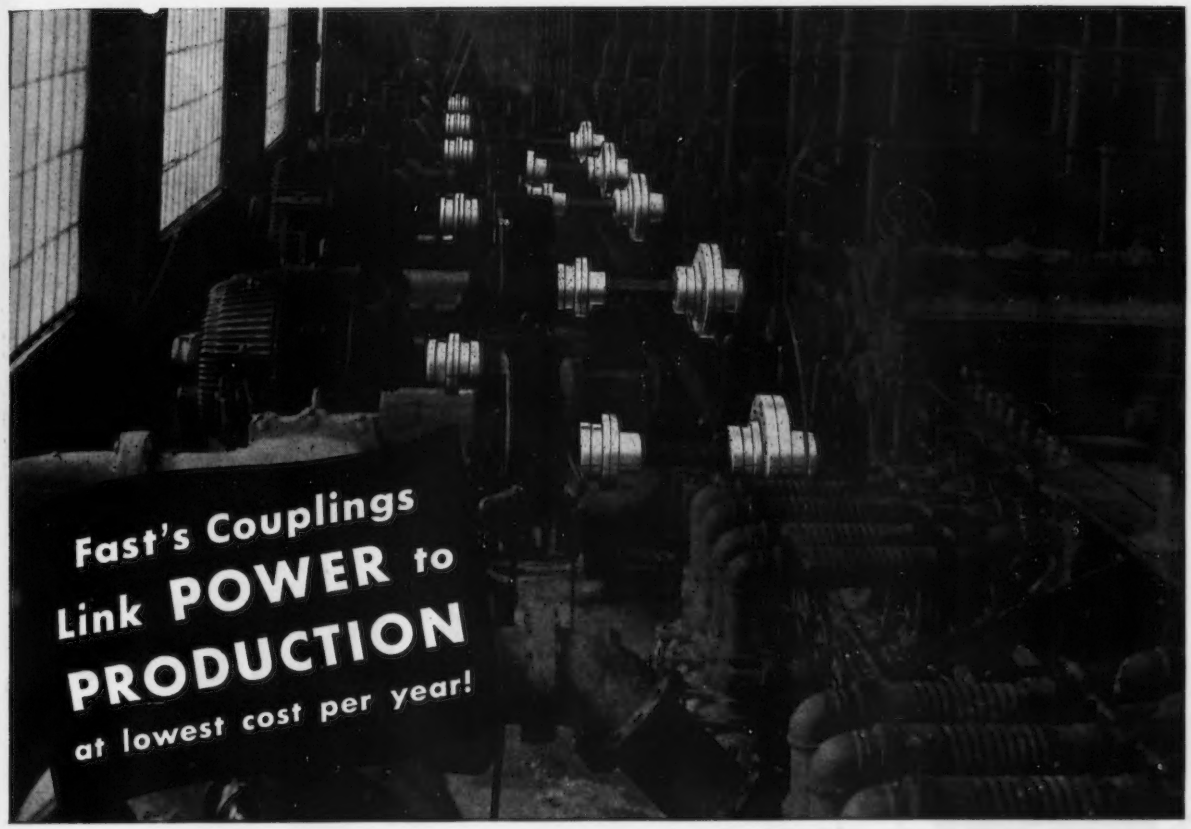
1. Faster Drying Rate
2. Longer Felt Life
3. Uniformly High Paper Quality
4. More Re-Orders—Less Sales Cost
5. Increased Production
6. Cleaner Felts
7. More Profit Per Pound

Let us show you how we can make good for you on these 7 big advantages. Write today for complete information and quotation on your requirements.

THE MANCHESTER MACHINE COMPANY

1711 CENTRAL AVENUE • MIDDLETOWN, OHIO

SPECIALISTS IN PAPER MILL MACHINERY AND COMPLETE REPAIR SERVICE



Over half a million FAST'S Couplings now in use!

THROUGHOUT the paper industry, Fast's are recognized as the most dependable couplings on the market! Year in, year out, Fast's continue to *outlast the equipment they connect* . . . saving paper mills time, maintenance and money by eliminating costly coupling failures.

When you specify Fast's in your mill, you can forget about coupling worries. Actual cases on record show many Fast's have been in continuous operation for 25 or 30 years without trouble. *And every major producer of high-speed equipment now uses Fast's Couplings!*

KOPPERS®

FAST'S
THE ORIGINAL
GEAR-TYPE
Couplings

INDUSTRY'S STANDARD FOR 32 YEARS

For complete information, with drawings, specifications and photographs, write for our free catalog. Address your letter to: KOPPERS COMPANY, INC., *Fast's Coupling Dept.*, 371 Scott St., Baltimore 3, Md.

Here's How FAST'S Save You Money

Free Service—Koppers free engineering service assures you the right coupling for the job.

Rugged Construction—Fast's still maintains its original design, without basic change or sacrifice in size or materials. Result: freedom from expensive coupling failures.

Lowest Cost per Year—Fast's Couplings usually outlast equipment they connect. Their cost may be spread over many years!

KOPPERS COMPANY, INC., *Fast's Coupling Dept.,*
371 Scott St., Baltimore 3, Md.

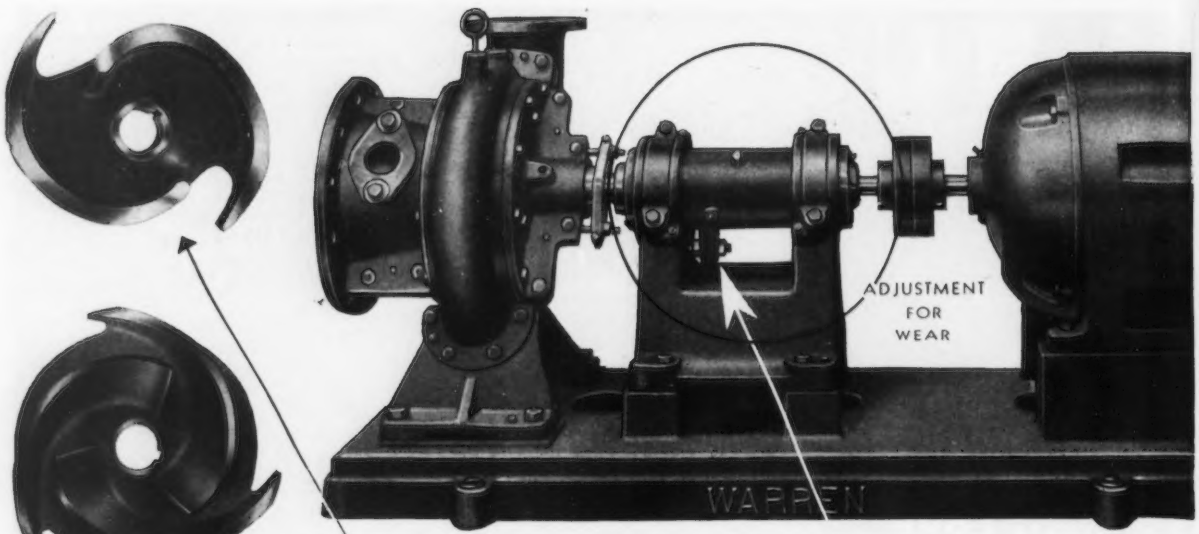
Gentlemen: Send me Fast's Catalog which gives detailed descriptions, engineering drawings, capacity tables and photographs.

Name.....

Company.....

Address.....

City..... *Zone*..... *State*.....



All for one...

but not one for all

The heart of a pump is the IMPELLER, and in each type and size of Warren Stock Pumps FIVE different impellers are available, each designed specifically for five different operating services, yet they all fit the same size and type of pump.

Each of these impellers "washes its own back" . . . in other words, the Eductor Vanes with which they are equipped, and pioneered by Warren, keep the space back of the impeller pumped free of fibre or grit, reduce pressure on the stuffing box and insure long packing life.

Back of typical Warren Impeller showing Eductor Vanes

Another feature of Warren Stock Pumps is the adjustment for wear between open impellers and suction liners. Inevitable wear increases the clearance between these two parts, and adjustment to reduce this clearance is provided by a simple adjustment screw. This results in less frequent replacement of liners.

The foregoing, and many other special features, make it advisable to specify:

PP-25

WARREN PUMPS

WARREN STEAM PUMP COMPANY, INC., WARREN MASSACHUSETTS

ADD A STEP !

When the soldiers of Alexander the Great complained to him that their swords were shorter than those of the enemy, he replied, "*Add a step to yours.*"

If the pinch of competition is troubling you, take a tip from Alexander the Great and "add a step" by coming South.

Our experienced plant location service is extended you without obligation or cost. All negotiations are confidential.

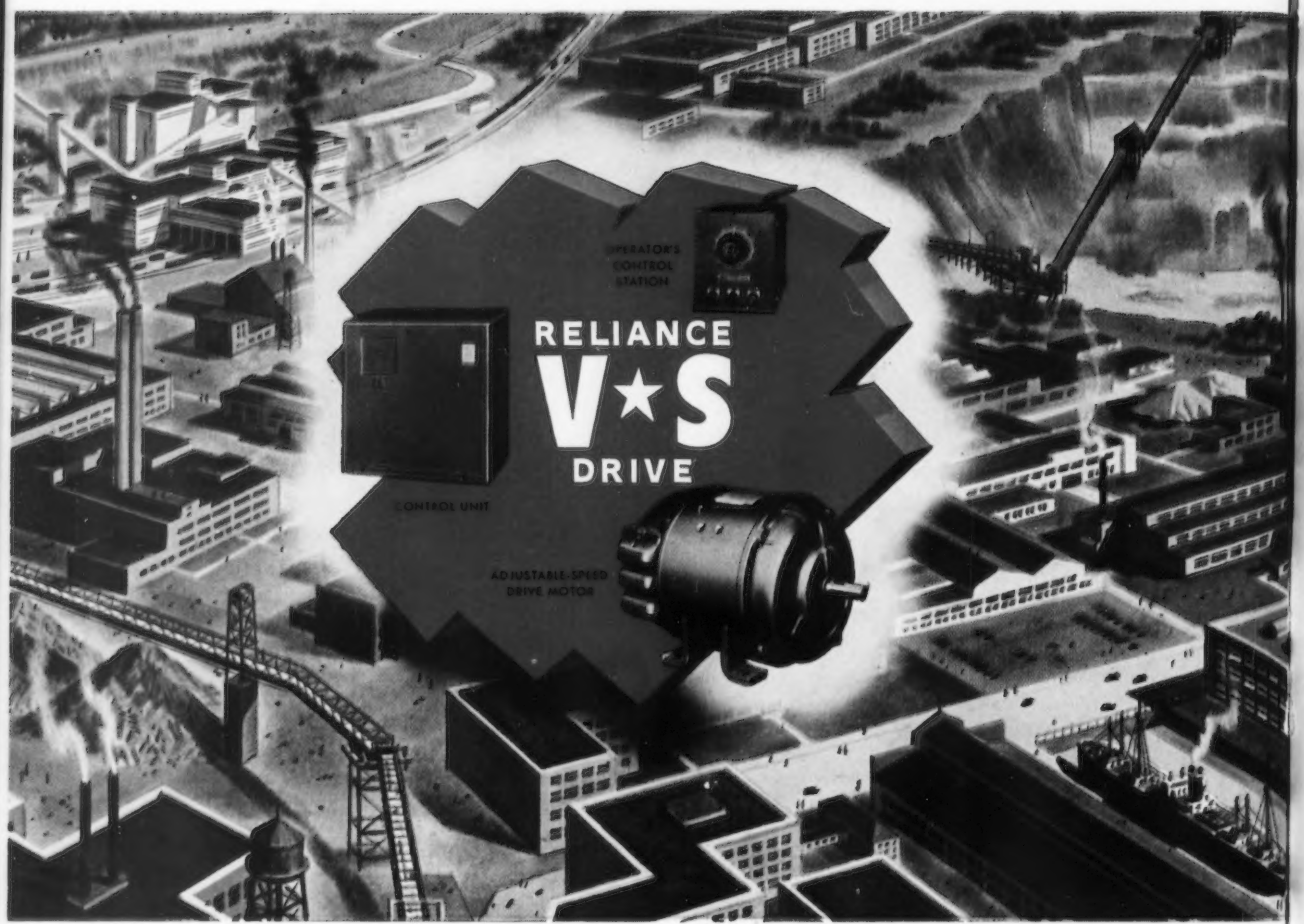
Address:
Warren T. White,
Assistant Vice President,
Seaboard Air Line Railroad,
Norfolk 10, Virginia.

GROW with the GROWING SOUTHEAST!

SEABOARD AIR LINE RAILROAD

THROUGH THE HEART OF THE SOUTH

6 reasons why



It's the Experience that Counts . . .

RELIANCE V★S
is the result of nearly 50 years' experience in the engineering and application of Adjustable-speed Drives.

Write today for important *NEW* data on Reliance V★S Drive (3/4 to 300 hp.) and how it can give you greater flexibility of operation to increase production and lower costs. Ask for V★S Drive Bulletin D-2311.

RELIANCE V★S *is important to you*

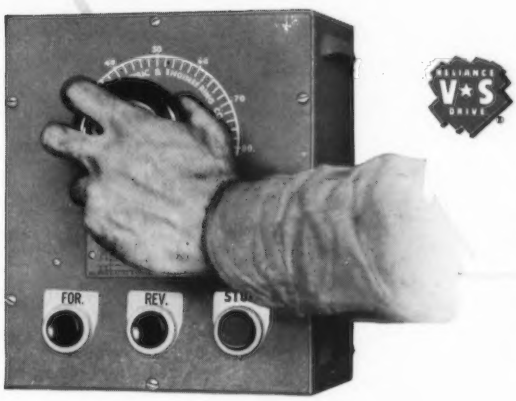
quick starting — without use of clutches; smooth action protects fragile materials.

quick, smooth stopping of any load through positive electrical braking which never wears out or needs adjustment.

controlled acceleration and deceleration—your operator can increase or decrease speed at any desired rate; provides for best machine performance.

unlimited speed changes over a wide range permit selection of the right speed for machine, material and operator to secure maximum production.

inching, jogging or creeping through adjustable slow speeds; your operator can slow down a machine for inspection, then accelerate quickly and *exactly* to previous working speed.

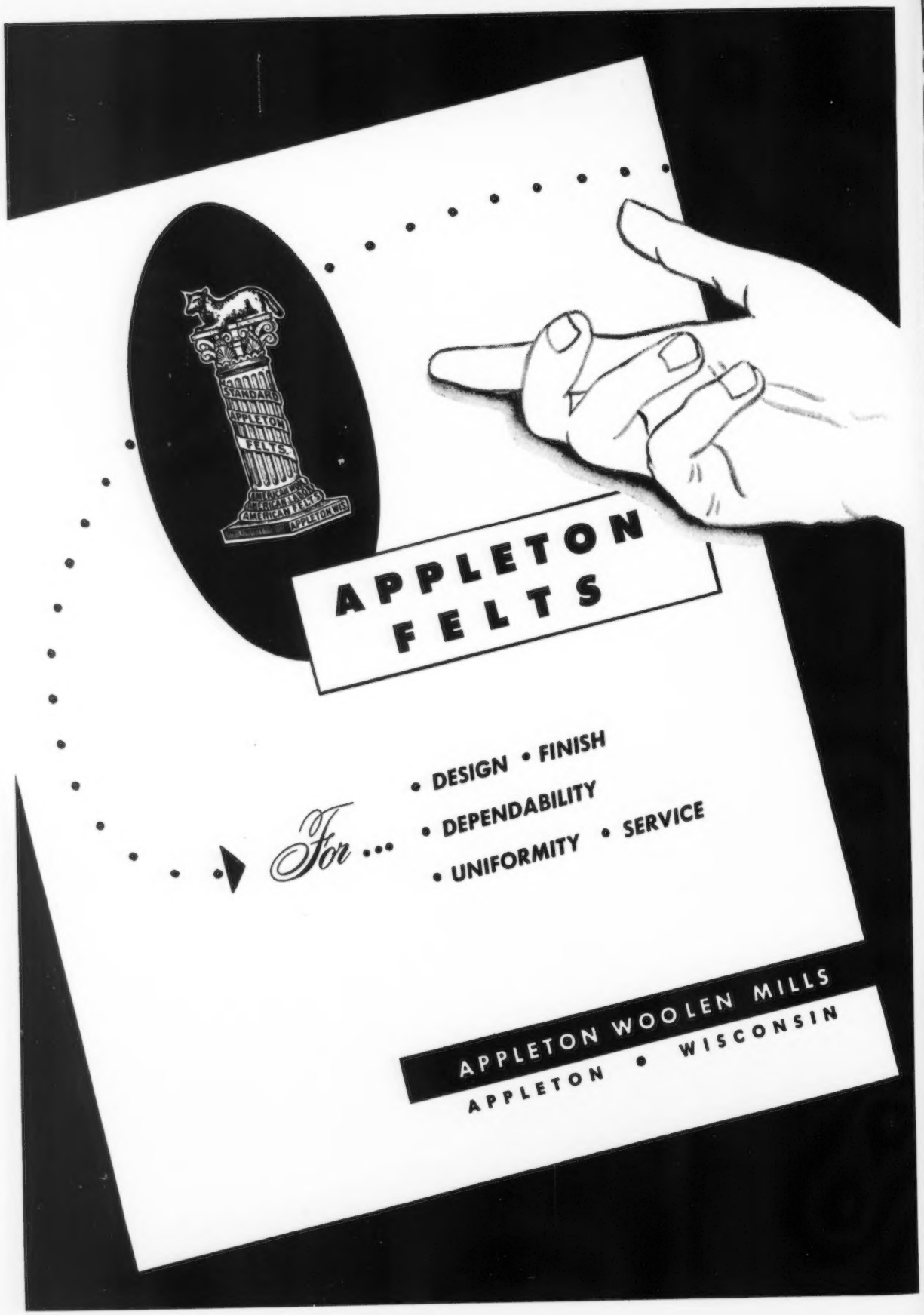


convenient-to-operate controls grouped and located where your operator can quickly, easily and safely control all functions of his machine. Operator fatigue is reduced—there is less production lag over the course of a shift—scrap losses are held to a minimum.

Sales Offices in Principal Cities

RELIANCE ELECTRIC AND ENGINEERING CO.

1099 Ivanhoe Road, Cleveland 10, Ohio • Canadian Division: Welland, Ontario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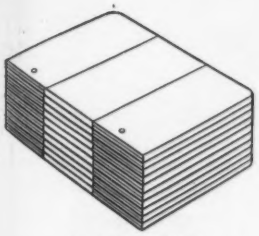
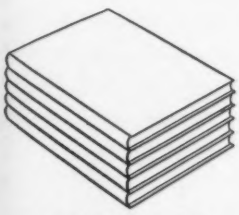
series E is your

wrapping answer!



Loose Leaf Fillers



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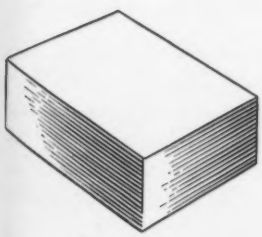

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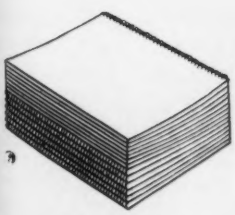

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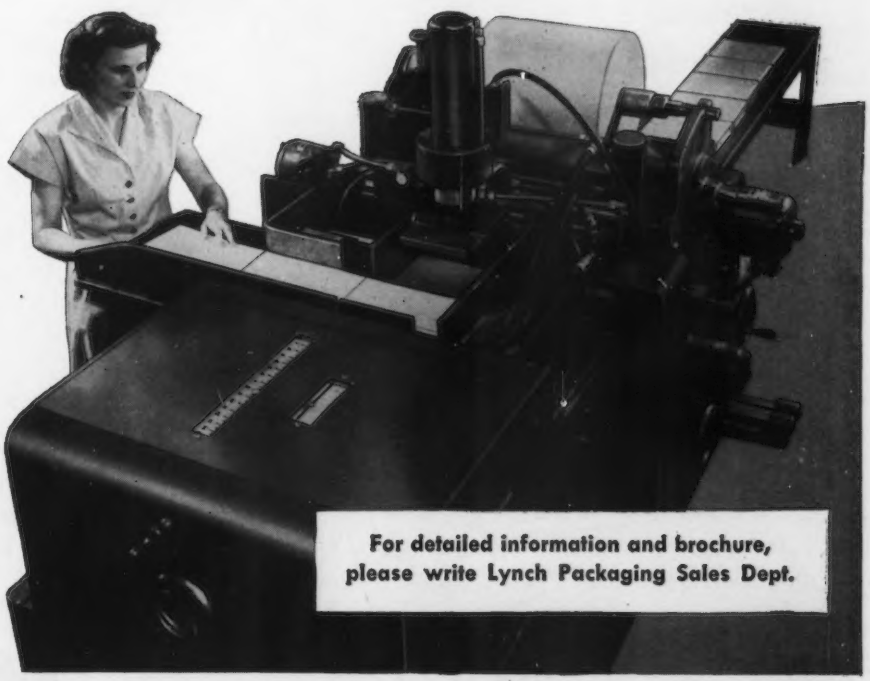

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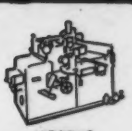

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News about

B. F. Goodrich Chemical *raw materials*

5 big improvements for your paper- *with Hycar!*

- Softer yet stronger
- Better absorption resistance
- Improved tear and wet strength
- Cloth-like feel
- Smooth-draping sheets

HYCAR-impregnated paper can help give you better paper products—give you more saleable products, too. Bags, protective wrapping, tape backing, shelf covering and imitation leather base are typical of the many uses for paper improved with Hycar.

You'll find Hycar latex easy, safe and economical to use. It may be added to paper before or after sheet formation. No dangerous or inflammable solvents are needed. No costly recovery system or vulcanization equipment is required.

Besides its use with paper, Hycar has many more useful applications. It is used for modifying other resins; for making phenolics tough rather than brittle. Non-migrating and non-volatile, it is ideal for permanently plasticizing vinyl resins.

Hycar-based adhesives can permanently bond paper, wood, leather, aluminum foil and vinyl films to themselves as well as to other materials. For technical bulletins and helpful advice, please write Dept. HM-12, B. F. Goodrich Chemical Company, Rose Building, Cleveland 15, Ohio. Cable address: Goodchemco. In Canada: Kitchener, Ontario.

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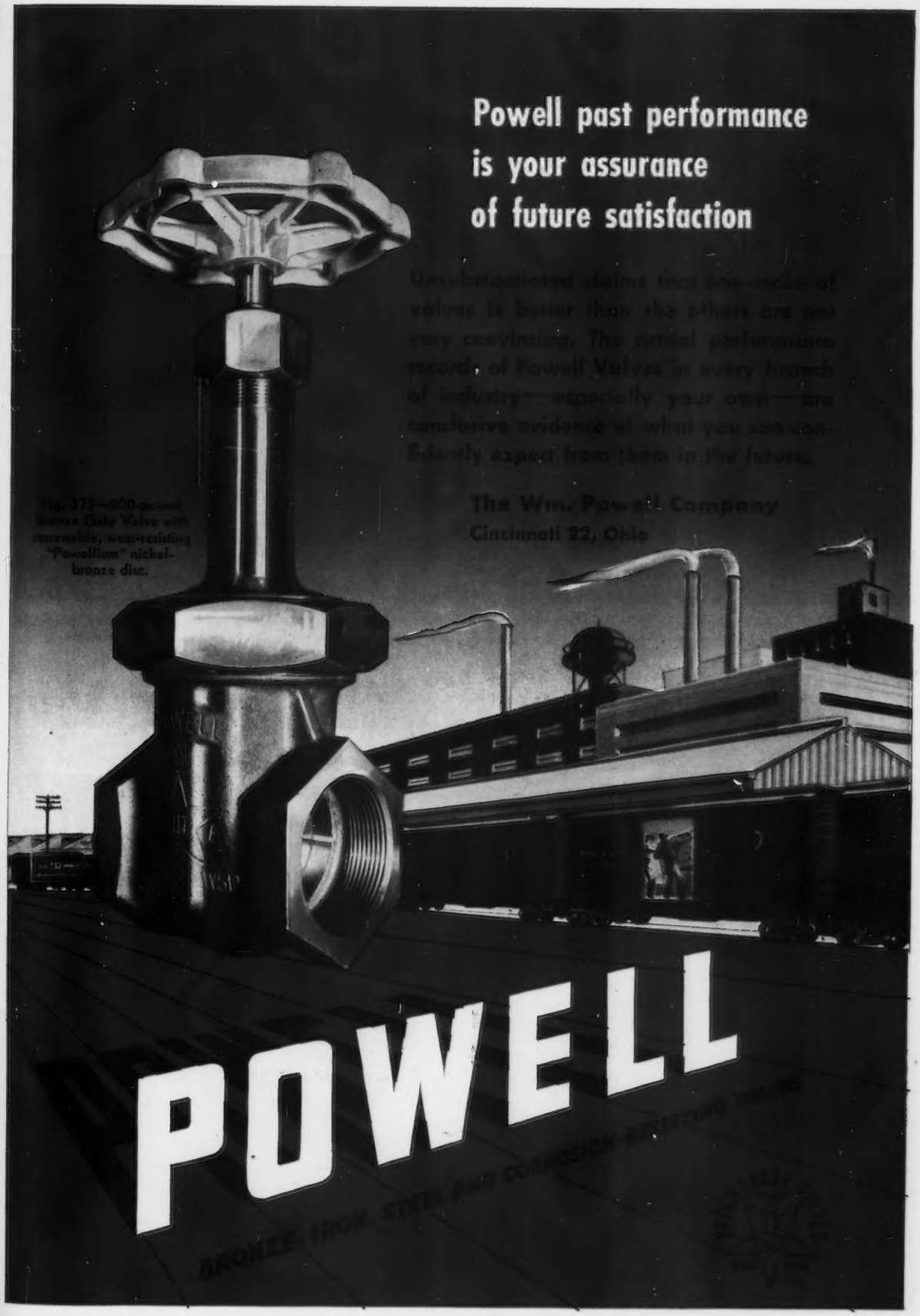
Hycar
American Rubber

GEON polyvinyl materials • HYCAR American rubber • GOOD-RITE chemicals and plasticizers • HARMON organic colors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is your assurance
of future satisfaction
No. 375—900-pound Bronze Gate Valve with renewable, wear-resisting "Powellium" nickel-bronze disc.
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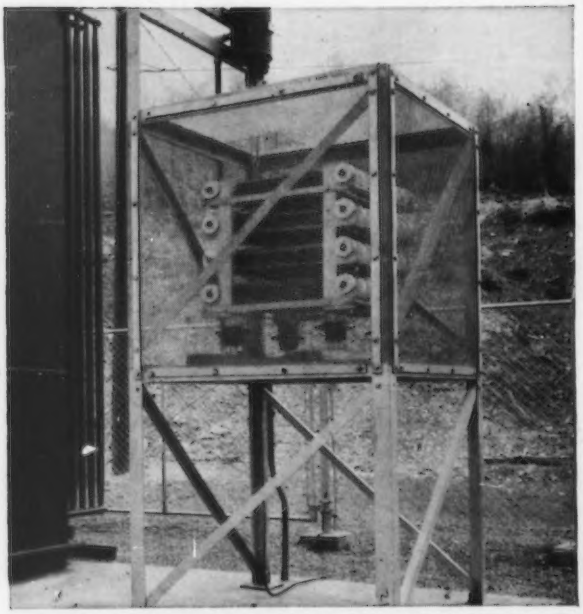
ENGINEERING REPORTS:

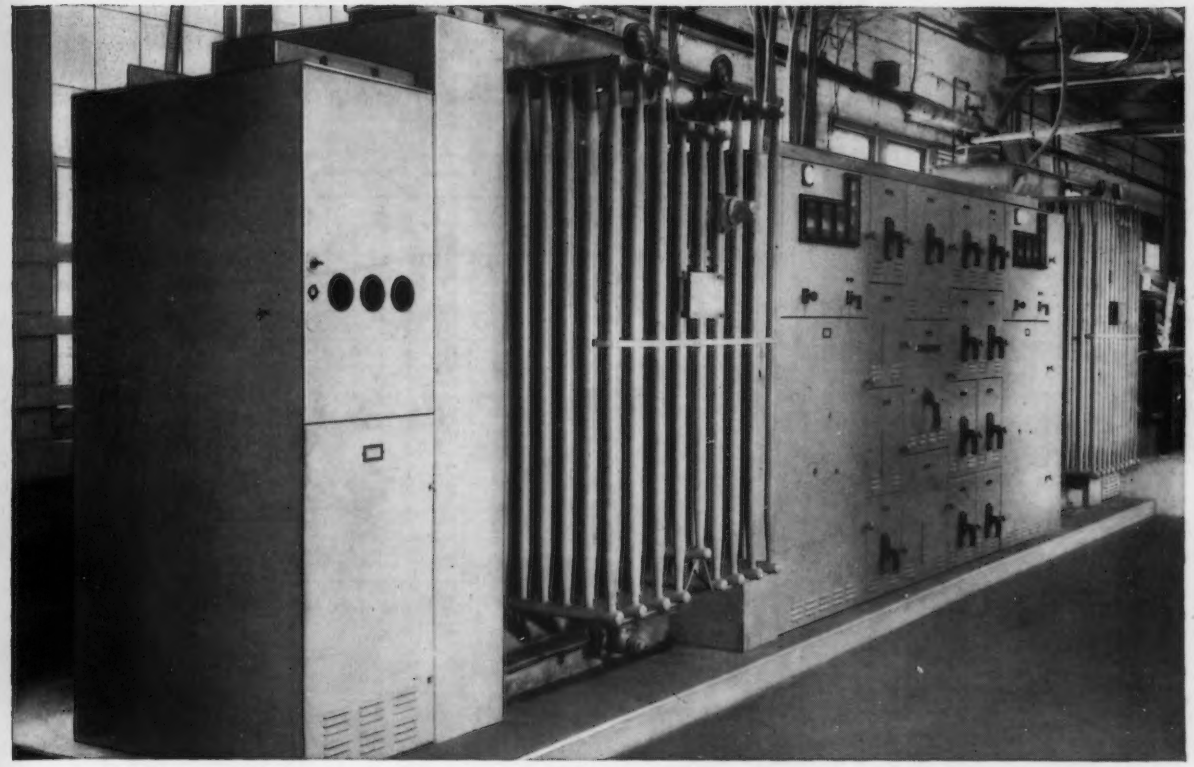
AMPLE IC. G-E metal-clad switchgear at Gardner has ample interrupting capacity for both present load and future expansion. Alfred Clegg, power house chief, likes the operating convenience of centralized control for main power circuits.

Modern power distribution system



NEUTRAL GROUNDING provides better over-all system operation. This resistor in the neutral of the 4160-volt system limits ground-fault current minimizing damage to equipment.

G-E APPLICATION ENGINEERS, with tools like this portable analyzer, can study your entire power system quickly—and recommend the proper system for your present and future load.



PROTECTS PRODUCTION. This 3000-kva G-E double-ended unit substation is one of two that insure against complete shutdown in stock preparation areas by providing an alternate 480-volt power source via secondary-selective arrangement.

protects production at Gardner

Secondary selective arrangement also adds flexibility for future expansion, more safety for personnel—neutral grounding minimizes equipment damage due to ground faults

Recently the Gardner Board and Carton Company of Lockland, Ohio, realizing that modern paper-making machinery does a continuous, high-tonnage job only when supplied continuously with adequate electric power, modernized its plant's power distribution system. Completely engineered and equipped by General Electric on an economical step-by-step basis, the new system includes such modern engineering advances as these:

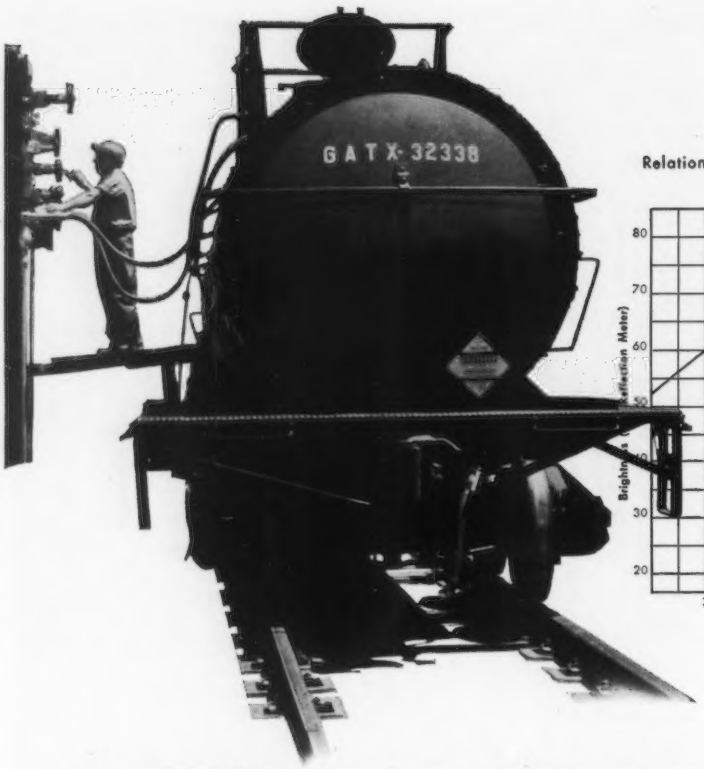
"Building-block" load-center unit substations that reduce power distribution costs and make future expansion easier—factory-assembled metal-clad switchgear that cuts installation cost and protects equipment and feeders—high-voltage power distribution for full voltage at the motors and higher operating efficiency—a secondary selective arrangement that safely provides a dual power-supply route for greater reliability and continuity of production—and neutral grounding of both the 4160- and 480-volt systems for greater safety to personnel and lower over-all downtime for outages.

Let your local G-E apparatus sales representative tell you how G-E engineers can analyze your entire power system quickly, and help you select the proper equipment to fit your plant's needs.

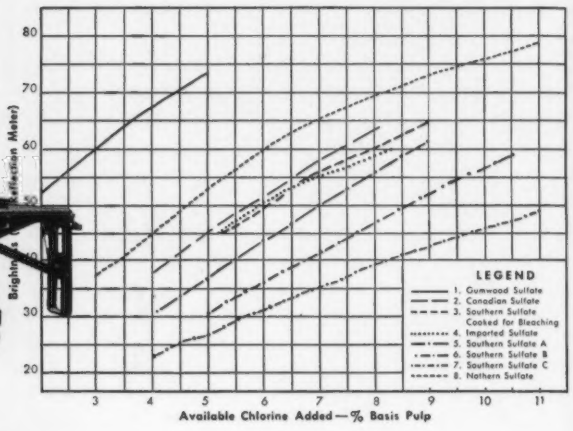
Meanwhile, write for bulletin GEA-5521, "Power System Equipment for Pulp and Paper Mills" and technical article GET-1181C, "Neutral Grounding of Industrial Power Systems." Section 655-12, General Electric Company, Schenectady 5, N. Y.

Engineered Electrical Systems for Paper Mills

GENERAL ELECTRIC



Relation of Brightness to Available Chlorine Added in Single Stage Hypochlorite Bleaching of Several Sulphate Pulps



Available Chlorine Added—% Basis Pulp

BRIGHTNESS CONTROL
begins here . . .

When you buy bleaching chemicals, don't overlook the all-important "how-to" that follows the shipment into your plant; helps you handle and use it most effectively and most profitably; saves you processing dollars; gives you the product grades you want.

Hooker Technical Service works closely with you to solve problems of handling chlorine and caustic soda in the most efficient, economical and safe manner. This assistance is based on years of service to the pulp and paper industry.

Hooker Chlorine and Caustic Soda, produced in the efficient "S" Cells at Niagara Falls and Tacoma, are well suited to your processing needs. They are shipped in properly conditioned and inspected tank cars, on carefully planned schedules that tie in with your production needs.

SEND FOR THIS HELPFUL BLEACHING DATA

Bulletin No.

201 Process and Equipment for Making Bleach Liquor for Use Without Settling

211 Chemistry of Bleaching Chemical Wood Pulps

214 What Do We Know About Bleaching?

236 Importance of pH and Catalysts in Bleaching Operations

242 Production and Use of Unsettled Bleach Liquor

243 Procedures and Brightness Grades in Bleaching Sulfate Pulps

From the Salt of the Earth

HOOKER ELECTROCHEMICAL COMPANY

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ASTEN

dryer felts

We like paper and it likes us

ASTENS are made with just the right balance of porosity and absorbency to fit your product. That's one of the reasons why they'll get along famously with your grade under your mill conditions.

Economy in the long run

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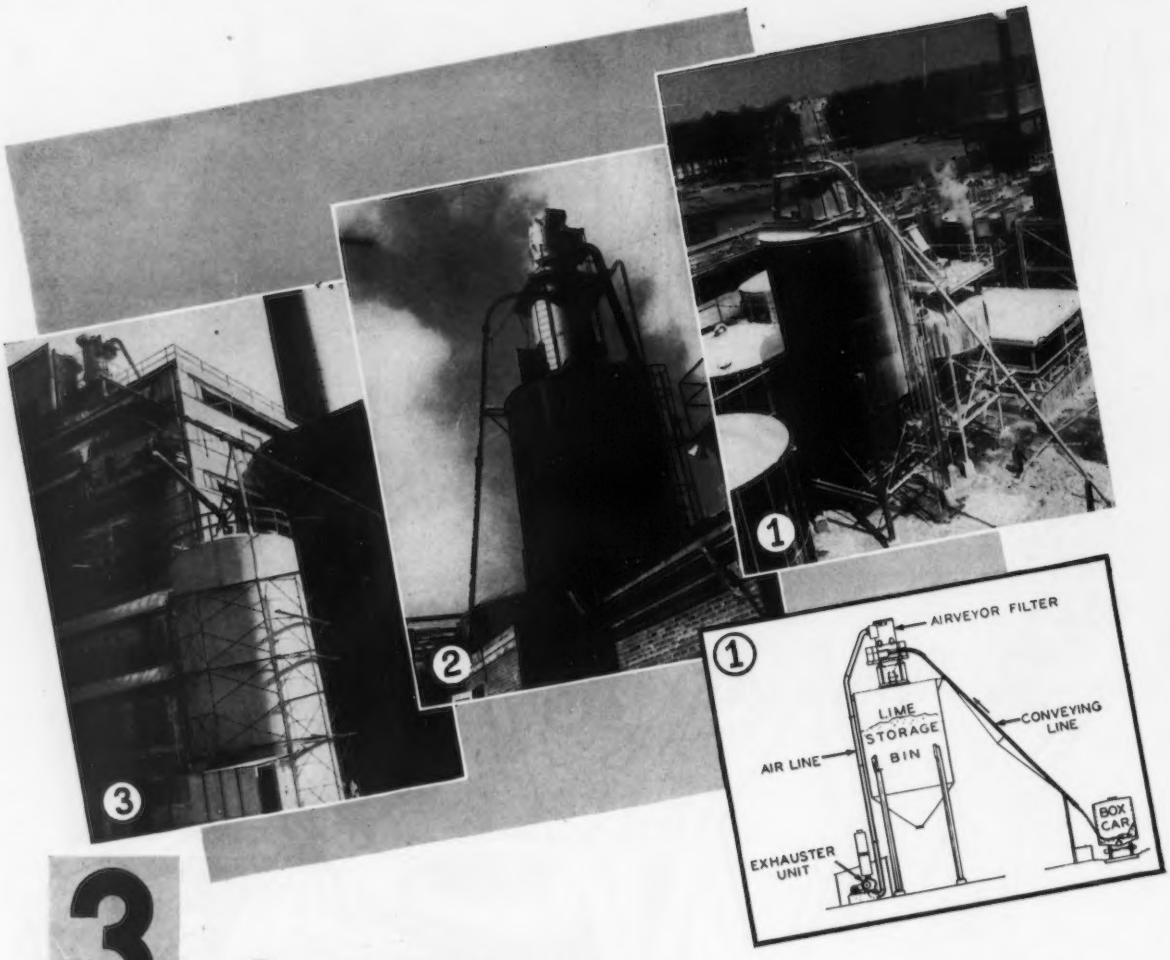


3 AIRVEYOR® SYSTEMS work for RIEGEL-CAROLINA

When the new 200-ton pulp mill of the Riegel-Carolina Corporation, Acme, North Carolina, was designed and built, they selected and installed Airveyors for handling mill-supply chemicals.

3 *Airveyors are in use:*

1. Unloading pebble lime to storage for use in the caustic plant. Unloading rate 10 tons an hour.
2. Unloading pebble lime and soda ash to storage for use in the bleach liquor making plant. Capacity 7½ tons an hour.
3. Unloading salt cake to storage, reclaiming from storage for delivery to mix tank in the Kraft mill recovery building. Handles 7½ tons an hour.

Many important pulp and paper mills throughout the country are finding new savings with Fuller Airveyor systems for the handling of raw paper-making materials. Each installation is custom-built to meet specific requirements, determined, after careful study, by Fuller engineers, with years of experience in the field of pneumatic conveying. Fuller engineers are at your service, to offer their advice, without any obligation. It could be a means of finding new cost savings in your materials-handling operations.

Fuller
CONVEYS BY AIR
. . . NOTHING MOVES BUT THE MATERIAL

A-165
1943

FULLER COMPANY, Catasauqua, Pa.

Branch offices

Chicago—San Francisco—Los Angeles—Seattle—Birmingham

DRY MATERIAL CONVEYING SYSTEMS AND COOLERS . . . COMPRESSORS AND VACUUM PUMPS . . . FEEDERS AND ASSOCIATED EQUIPMENT

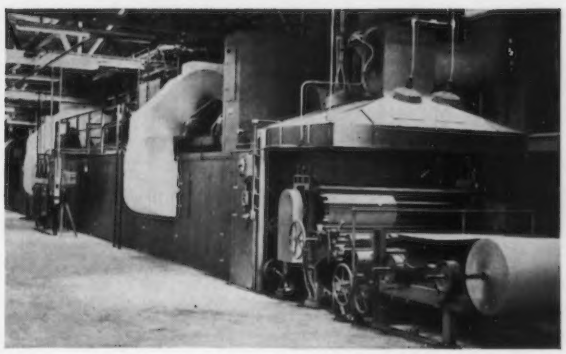
For Its Better-Than-Average Design and Construction

ROSS-WALDRON

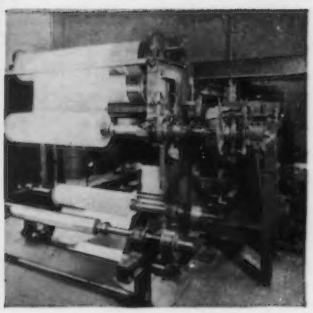
CONVERTING EQUIPMENT

is the outstanding choice of the leaders throughout the industry

Exterior view of ROSS-WALDRON Tower Treater



ROSS-WALDRON treating apparatus with zoned drying unit



Winding and Unwinding

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EMBOSSING √
IMPREGNATING √
LAMINATING √
TREATING √
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DRYING √
CURING √
HANDLING √

Ross-Waldron Converting Equipment is available for papers, textiles, films and foils.

PROCESSING UNITS and COMPLETE SYSTEMS

In the planning and production of a paper converting machine line, there is no substitute for experience. And the most successful converters know the value of the longer experience and knowledge of processing requirements that ROSS-WALDRON can bring to their particular problem. ROSS-WALDRON'S engineering, testing and manufacturing facilities can effect savings in time and money in providing better-than-average equipment and results. See our catalog in Sweet's M.I. File or write us for particulars.

see our CATALOG in SWEET'S FILE MECHANICAL INDUSTRIES

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J. O. ROSS ENGINEERING CORPORATION

MANUFACTURERS OF AIR PROCESSING SYSTEMS

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ROSS ENGINEERING OF CANADA, LIMITED, MONTREAL, CANADA

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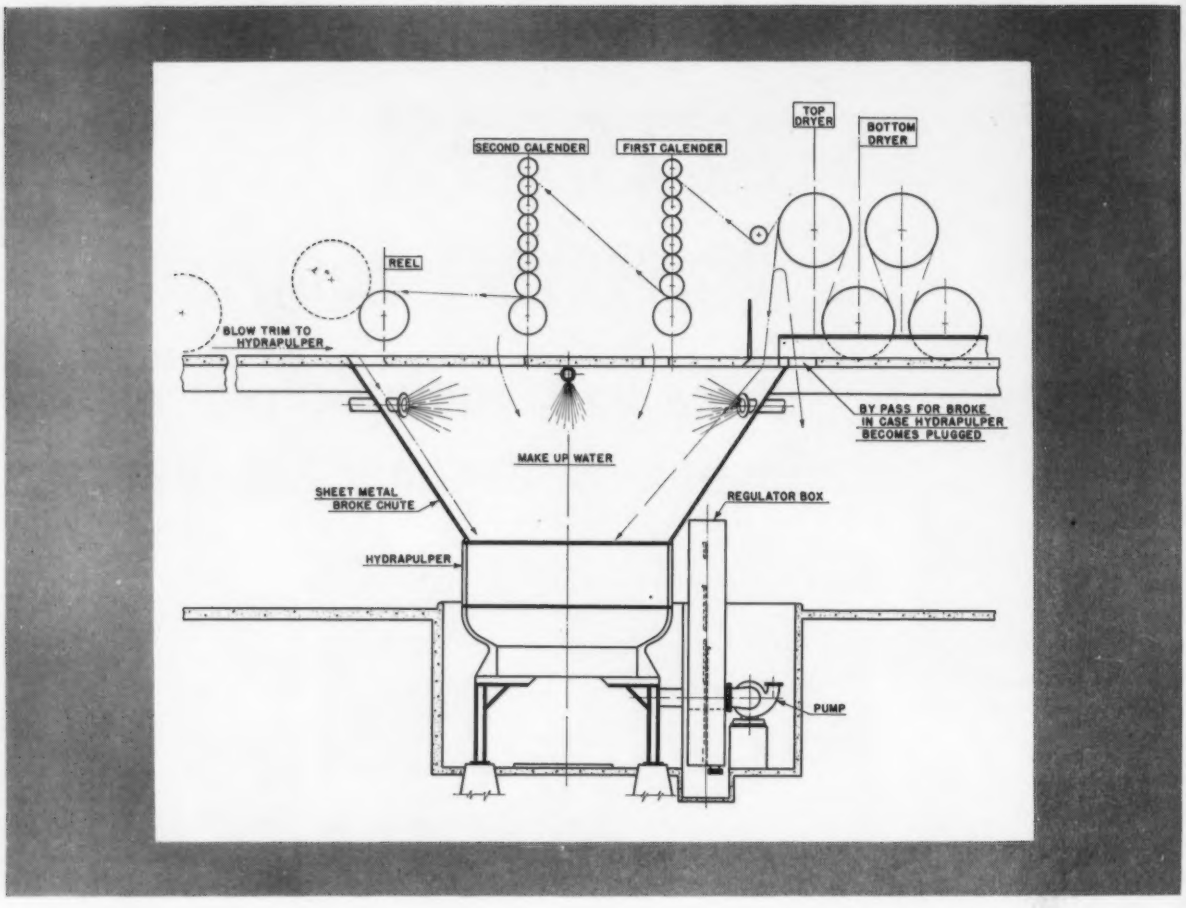

Broke Handling at its Best

How does this broke handling arrangement strike you?

1. Hydrapulper* below and between the last dryer and first calender.
2. Drop broke direct from dryer.
3. Drop broke direct from calenders.
4. Blow broke from finishing thru tube.

ADVANTAGES—no trucking—no dragging of broke thru dirt and oil. No confusion on machine room floor. Everything close to 100% automatic.

Special broke Hydrapulpers of any required capacity, with or without special flared top or other special broke handling features.

Have us identify several such broke handling installations for your inspection.

*Trade Mark

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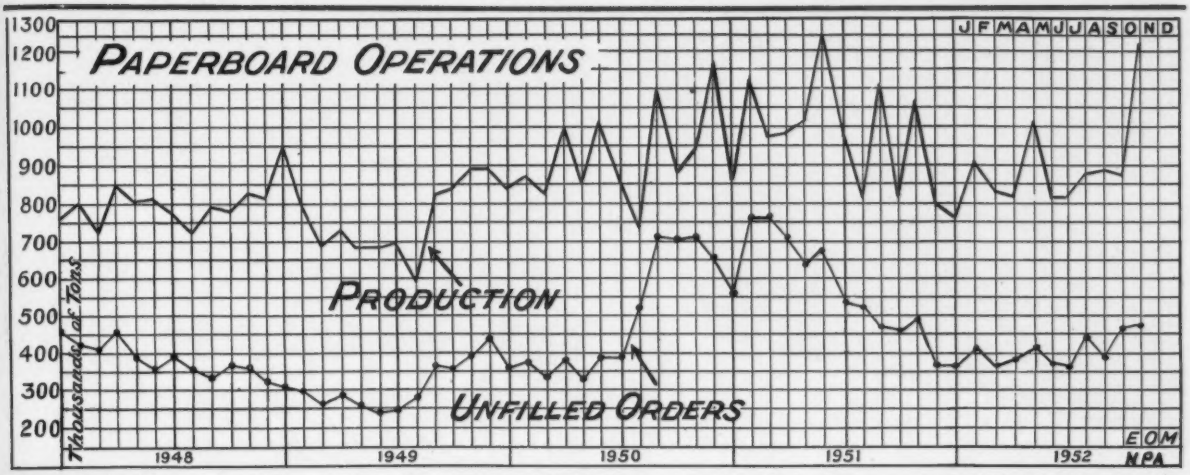
OUR BUSINESS



Brief of Important Figures

Source	Production	WEEK ENDING Nov. 1, '52	Oct. 4, '52	Nov. 3, '51
APPA	Paper Production Percent Capacity[3]	90.5	90.3	100.1
APPA	Unbl. Kraft Paper Production Percent	82.0	77.2	105.7
NPA	Paperboard Operating Ratio Percent Inch Hours	97	95	85
		Sept. 1952	**Aug. 1952x**	**Sept. 1951**
APPA	Paper Production* (Except Newsprint and Building Papers) ....Tons	775,000	773,000	821,000
	New Orders ....Tons	804,000	749,000	811,000
	Unfilled Orders ....Tons	806,000	751,000	986,018
	Shipments ....Tons	748,000	765,000	811,000
		Oct. 1952	**Sept. 1952**	**Oct. 1951**
NPA	Paperboard Production ....Tons	1,222,424	875,455	1,055,647
	New Orders ....Tons	1,225,736	954,126	1,110,638
	Unfilled Orders ....Tons	452,959	459,907	487,788
	Our Customers Activities Index[1]	**Latest Mo.°**	**Previous Mo.°**	**Year Ago°**
FRS	Manufacturers Total Index	228	204	229
	Durable Mfg. Index	270	232	269
	Nondurable Mfg. Index	194	181	197
	Chemical Products Index	294	294	303
	Mfg. Food Products Index	185	174	189
	Printing and Publishing Index	157	145	166
ODC	Magazine Advg.-Printer's Ink Index	369	403	376
	Prices Index			
BLS	Consumers Price Index[1]	191.1	190.8	185.5
	Wholesale all Commodities[4]	112.1	111.8	113.7
	Wholesale Processed Foods	110.5	110.0	111.2
	Commodities other than Farm Products and Foods[4]	112.9	112.5	114.9
	Wholesale Pulp, Paper[4] and Allied Products	115.6	115.3	119.5
	Purchasing Power of Dollar, Consumers Prices[1]	52.3	52.4	53.9
	General Activity Index			
FRS	Mfg. Production-Worker Payroll[4]	130.5	121.7	128.4
	Unemployment Compensation Initial Claims (M)	733	1,585	950
	Miscellaneous Carloadings–Thousands of Cars	1,852	1,155	1,928
	Electric Output (Million KW hr.)	39,752	37,007	37,632
PTJ	Average 32 P & P Common Stocks as of Nov. 8	$34.82	$35.23	$38.19

[1] 1935–39 = 100 Unadjusted Index.
[3] For Five Weeks.
[5] New 6-7 day basis.
[4] New Index 1947–1949 = 100.
* For details see APPA Monthly Statistical Summary—September 1952 Estimated Figures.
° Latest Month Available on Request.
x Revised Figures.

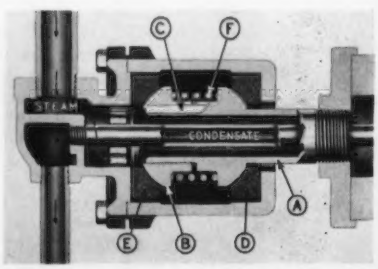
First choice in the east, too!

Mill problems may vary from one section of the country to another. But not the overwhelming preference for Johnson Joints.

In the eastern states — as in the midwest and throughout the entire paper industry — you'll find them far and away the favorite among all steam fits. More mills, and more machinery manufacturers, have adopted them than anything of their kind.

It is their packless, self-lubricating, and self-adjusting design that first put Johnson Joints so far ahead. It is Johnson's wealth of experience and continuing research that keeps them there. Whatever your needs there are time-tested Johnson Joints to fit the job precisely, and to pay their way out of savings in maintenance.

Picture shows Type B Johnson Joints installed on a paper machine in a Delaware mill. You'll find scenes like this repeated all over the east, and throughout the paper industry. Johnson Joints remain unchallenged in design, scope of application and performance records.



There's nothing else like it—Nipple (A) is connected to roll or drum. Collar (B) is keyed to nipple at (C) but fits loosely so pressure can fill entire housing and serve as sealing force. Seal ring (D) and bearing ring (E) are of special carbon-graphite; they eliminate all packing or need for lubrication. Spring (F) is for initial seating only; joint is pressure-sealed, consequently self-adjusting. Note space for lateral movement of rotating assembly, spherical seating for angular movement.

Write for Catalog JJ which has all the facts.

Products of The Johnson Corporation

828 Wood St., Three Rivers, Mich.

Rotary Pressure Joints • Compressed Air Separators and Aftercoolers
Direct Operated Solenoid Valves • "Instant" Steam Water Heaters

Paper TRADE JOURNAL

TRENDS

Raw Materials Trading Is Dull Paper Demand Shows Pickup

Current market activity—or lack of it, some would say—is being determined by factors of demand-outlook and the date. With but six weeks to go to the year's end, the size of raw materials inventories weighs heavily.

Snatches of remarks heard on the street aptly describe today's trading. Said the first, "Everybody's playing possum." And said the other, "When there's something good at a cheap price, I buy it."

Though the immediate outlook for the paper and products market as a whole is one of gradual and sure improvement, the bent of the raw materials supply is not following the upward climb. Rather it appears to have hit a plateau wherein there is little activity.

A factor is the free market supply of pulps, waste papers, cottons, and practically all chemicals, which the mills seem to believe will continue for some time. Voiced by suppliers, however, is the hope that consumers are not going to be caught short of supplies as the market gathers strength early next year.

Evidence of Buyer's Market Seen in Pulp Downgrading

Such a condition could so easily develop in wood pulps where mills count on Swedish pulps to balance their supply. By mid-January, it is likely that navigation from northern ports will be closed for the season.

Continued reports of downgrading in market wood pulps leave no room for doubt that a certain amount does exist. Where there are special prices, however, they are being handled on such a confidential basis that even here in New York, no one can or will confirm them.

Known cases of downgrading are mostly in overseas grades, and are seen as pure evidence of the free supply and the buyer's market prevailing. Generally speaking, it is said, all primes are being held at quoted levels; but one can buy the best quality pulps at the low of the contract range.

Unbleached sulfites in free supply . . . A quick rundown of market conditions for each of the chemical pulps follows:

Bleached Krafts.—No particular weakness exists anywhere in this grade, though downgrading has been reported on one Canadian brand and one Swedish. Supply is adequate and increasing from North American sources. The U.S. $140 delivered price is the lowest for prime pulp.

Bleached Sulfites.—Canadian and U. S. grades of bleached sulfite are strong at $140/145 for the former, $140 for U. S. Some rejects of a Canadian brand have been reported for less than contract price. Swedish and Norwegian grades also are firm at contract prices. Austrian pulps are being offered at $125 on dock Atlantic ports, a price which to nearby mills represents a saving. In some quarters, the pulp is classed as a secondary grade.

Unbleached Sulfites.—Overseas pulps are being held firmly by most producing mills. Admittedly there are a number who are selling half-primes at reduced prices; others are being downgraded. Swedish stocks are heavy but, in view of high costs, for the most part there is no anxiety to dispose of primes at lower than today's level. On the whole, all primes are being held at or near the $110/115 level, OD, it is reported.

For the Canadian grades, the $135 price is held to be very firm, despite the fact that U. S. industry and agents contend that it is unrealistic, in view of the ample supplies of overseas primes being offered here.

Of all the pulps, dealers believe this to be the one grade in which a price dip should develop for the first-quarter. Speaking of the Canadian pulps as a whole, they express little sympathy for the plight of the *news* grades of sulfites which are a sideline for newsprint mills. Other Canadian grades are competitive in quality, though, priced at $135 delivered basis suffer a disadvantage with the overseas pulps so freely available.

Unbleached Krafts.—So far as the U. S. brands are concerned, no trace can be found of any being sold at or less than the $100 price. Agents aver that their principals just are not interested in selling lower than the $100 delivered price.

For the Canadian grades, reports of less than $100 cover sales to the extremely competitive export market. The lower quotes cover costs of transportation, it is said. So far as can be ascertained, there is no other price to this market. Spot buying is not heavy, and the price is as low as producers want to go.

On the overseas pulps, it is believed that their high quality is being offered at a "cheap price" to regain a market which was lost to the abundant supply of U. S. southern kraft pulps and to the Canadian grades.

Spot market price has been named at $95/100 Atlantic seaboard, though contract levels are $100/105. In view of the higher costs of production and the costs of pulpwood in Scandinavia, every such sale is held to be an invitation to "ultimate bankruptcy." Auctions for the woods supply in Sweden are now underway, and our advices are to the effect that the prices do not allow for the present low prices for pulps.

Consumer stocks are ample . . . So far as the larger consumers are concerned, their buying is limited. Stocks are ample to their improving demand, their needs are protected with reservation contracts on U. S. and Canadian pulps, and they are indifferent to the overtures of Scandinavian mills. They have all the pulp they want and are not buying more.

Small Change In Waste Papers

Whichever way you choose to read it, it's right. On today's market, there is only small change in waste paper trading; and there has been little change in waste paper prices since last reports.

In some areas, the atmosphere is depressed by the long famine which now is accentuated by the free supply and spot offers of wood pulp. Also influencing the market is the upgrading of paper quality with which papermakers are meeting competition.

Not all mills are interested, to be sure; not all care to disturb their furnish. The trend is sufficient, however, to depress the price of pulp substitute grades. (See Prices page for details.)

White newsblanks are influenced by the overseas groundwood price. At $66 on dock price, the Swedish groundwood challenges the price of white newsblanks of $65/70. However, the groundwood market has been tightened by the extremely dry Fall, and to press time the newsblanks price was unchanged.

In the New York area, ledger stock, white and colored, is scarce. Wanted in normal quantities, it is in shorter supply because printers are not cutting—an indication of the adequate inventory condition which still exists on this grade in the hands of consumers. E. P. N.

Paperboard Production (Tons)*

	Nov. 1 1952	Oct. 25 1952	Nov. 3 1951	Month of October
Production	244,854	242,598	207,910	1,222,424
New Orders	226,485	200,915	297,394	1,225,736
Unfilled Orders	452,959	472,987	487,788	452,959
% of Activity	97	97	85	96

* Source: National Paperboard Assn.

Vanzyme discs

EASY TO
STACK AND HANDLE

STARCH CONVERTER

for

TUB AND CALENDER SIZING
COATING AND
LAMINATING ADHESIVES

Increase
ACCURACY
ECONOMY
EFFICIENCY
AND SPEED

R. T. VANDERBILT CO., Inc.

230 Park Avenue, New York 17, N. Y.

Power Shortage Downs C-Z #2 Machine

Crown Zellerbach's newsprint mill in Port Angeles, Wash., was forced to shut down one paper machine on November 7, because of the general Pacific Northwest power shortage. Resident Manager Ray Schadt said this reduces its newsprint production approximately one-third.

Shutdown of No. 2 paper machine reduced production labor 450 man hours per day, equivalent to approximately $1,000 payroll per day. Part of the 55 men involved will continue working on reduced hours.

The particular paper machine shutdown depends upon the immediate power situation. No. 2 is the intermediate size machine. Next week No. 2 might resume and the smaller No. 1 machine shutdown, depending on the power fluctuation. On the other hand, continued lack of rain during the next week might force a greater shutdown.

Furthermore, on November 17, a government order will reduce all firm power contracts to large power users by 10 percent, due to the extreme power shortage.

Certificates of Necessity Granted

The Defense Production Administration has announced as of November 5 the grant of two certificates of interest to the paper industry.

Forty percent was allowed on the certified amount of $1,007,000 to Potlatch Forests, Inc., Lewiston, Idaho, for facilities to produce wood pulp from sawmill waste.

Gulf Oil Corp., Philadelphia, Pa., was granted 70 percent on certified amount of $1,130,800 for expanding their sulfur recovery facilities.

Sawyer Advises Reduction In CMP Controls

WASHINGTON, D. C. — A gradual reduction in CMP controls, but with retention of authority to reimpose these restrictions, is advocated by Secretary of Commerce Sawyer, following a swing around the country.

Conferences with representative business men, he said, convinced him these want controls ended as rapidly as practicable.

Edith Walker, Left, of Emergency Meals Div., British Ministry of Food and Ellen Rutham, Right, Chief of Emergency Feeding of CDA, View Stockpile of Two Million Cups Gathered By Paper Cup & Container Institute for Disaster Feeding in Baltimore and Washington. Miss Walker Is on U. S. Lecture Tour at Invitation of CDA.

Major Break-Down at Gaylord

A report has been received that the turbine drive on Gaylord's No. 4 machine recently ran wild during an early morning shift. This is the first major breakdown at the Gaylord Container Corp.'s, Bogalusa, La., mill in nearly thirty years.

The trouble began when the governor on the steam-turbine drive failed to reduce the drive speed when the load was taken off the turbine shaft during a power failure of the air supply to No. 4 machine.

The 216 ft. by 4 in. shaft accelerated to such high speed that it twisted to pieces and ripped into surrounding electrical and steam lines. Pulleys flew about wildly and the concrete pillars supporting the shaft bearing broke into fragments.

Fortunately, none of the mill personnel were injured during the crack-up.

Gaylord officials hoped to receive early shipment of repair parts and restore the drive to operation with minimum delay. Meanwhile, the board production of No. 4 machine has been partially absorbed by the other Gaylord machines.

Crystallize Plans for Ohio Mill

The $30 million newsprint mill planned for Portsmouth, Ohio, will be known as the Emigh Ohio Valley Newsprint Co. It is to be constructed on 43 acres of ground at the east edge of the city. Two hundred tons of paper daily will be manufactured from old newspapers and rags. The first unit is expected to be completed by the spring of 1954 at a cost of $15 million. Three million, five hundred thousand to four million gallons of water will be obtained by damming the Little Scioto River. It was originally planned to build this mill somewhere between Cincinnati and Dayton.

Recommend Newsprint Mill for Grays Harbor Area

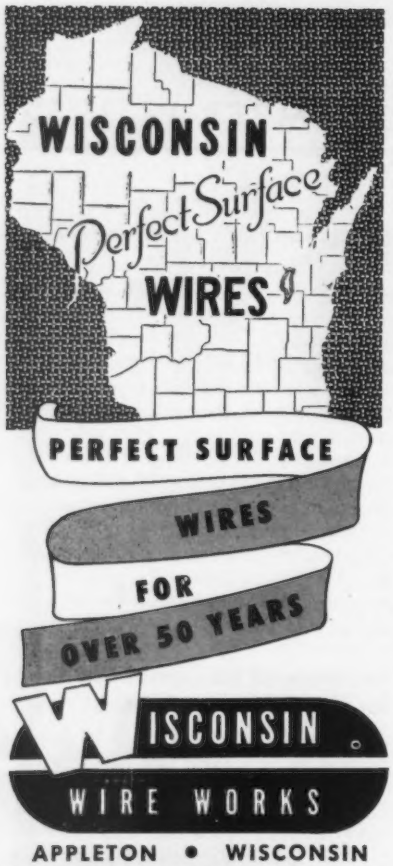
On the basis of a survey of paper demand in the West for the coming decade, Stanford Research Institute has recommended the establishment of a $48 million newsprint plant on the Olympic peninsula under sponsorship of newspaper publishers. It suggested a two-machine mill capable of producing about 170,000 tons annually.

Approve Ketchikan New-Type Waste Disposal System

The Territorial Water Pollution Control Board has approved plans for the Ketchikan Pulp Co's., waste disposal system for its plant at Ward Cove, Alaska. Construction is to start immediately. The system to be installed in the plant is a type wherein all wastes are recovered. The waste liquor is burned and used as a fuel in generating steam for the mill. Known as M.G.O. or magnesium oxide recovery, the system was developed at the Weyerhaeuser Pulp Co. plant at Longview, Wash.

Canadian Car Loadings

Car loadings on the railways across Canada in week ended October 14 increased to 849 cars of woodpulp against 767 cars in previous week but dropped to 2,380 cars of newsprint against 2,660 cars, with car loadings of paperboard, pulpboard and wallboard rising to 337 cars against 304 and paper other than newsprint declining to 443 cars against 484 cars, Canadian Government reports.



"I don't see how we ever ran this mill without it!"

one of world's largest makers of quality papers

Do your CLEANING Faster

—at Lower Cost

Have you seen the Hydro-Air Cleaner, that has *solved* the cleaning problem for many mills?

It scours the stock off of machine frames, screens, rolls, pipes, vats—*at unbelievable speed.* Saves chemicals. Mill men report saving 90% of their cleaning costs. Patented gun mixes high-pressure water and air; cleans delicate screens quickly without the slightest injury.

Write for Bulletin "P." Hydro Silica Corporation, Gasport, N. Y.

HYDRO-AIR PRESSURE CLEANER

Claim Faulty Labeling of Sheet Wrapping Tissue Bundles

Faulty and inadequate labeling of No. 2 sheet wrapping tissue in this area is seen as increased market competition on this grade. Faced with new evidence that packages, bundles, or boxes are being delivered without descriptive content marking and that consumers in some markets are getting short weight as a result, Tissue Association, Inc., 122 East 42nd street, New York, last week released to consumers and the trade press copy of a letter which was sent out to all sheet wrapping tissue manufacturers on the subject of adequate descriptive content marking.

"To All Sheet Tissue Manufacturers

Gentlemen:

RE: *Descriptive Content Marking*

It is alleged that recently sales of bundles, packages or boxes of sheet wrapping tissue have been made in some markets without any content marking on the wrapper or carton or even, it is claimed, in some cases with incorrect content labeling.

We had believed that the practice of plainly indicating the contents of all bundles, packages, or cartons of sheet wrapping tissue was so firmly established, both by custom and by law that no unmarked bundles, packages or cartons were being sold today. But if the reports to us are correct this is not the case.

We are therefore recommending to all manufacturers of sheet wrapping tissue that every bundle, package or carton sold by them carry the following information in lettering large enough to meet the requirements of State Weights and Measures Regulations.

Grade
Sheet Count
Sheet Size
Basis Weight
The Name of the Manufacturer or an Identifying Mark.

If an identifying mark is used, it should be made known to all distributors of that manufacturer's product so that if any question as to content marking arises, the distributor will be able to give the local Weights and Measures official the name of the manufacturers.

A copy of this bulletin is being mailed to the paper trade press, to the trade press in various industries which are consumers of sheet wrapping tissue and to Weights and Measures officials in all jurisdictions.

Very truly yours,
(signed) Ross A. Fife"

AMERICAN PAPER AND PULP ASSOCIATION'S PAPER PRODUCTION RATIO REPORT

(Production as per cent of normal capacity)

COMPARATIVE WEEKLY SUMMARIES

	Oct. 4	Oct. 11	Oct. 18	Oct. 25	Nov. 1
1952	90.3	90.0	90.5	92.4r	90.5
	Oct. 6	**Oct. 13**	**Oct. 20**	**Oct. 27**	**Nov. 3**
1951	101.0	100.3	100.4	100.5	100.1

COMPARATIVE MONTHLY SUMMARIES

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year Avg.
1951	99.3	101.3	101.9	102.8	102.2	100.1	88.6	97.7	94.3	100.3	98.0	90.0	98.0
1952	97.1	97.8	95.1	90.6	88.6	87.6	75.5‡	86.7‡	82.5‡	90.8‡			

COMPARATIVE YEARLY SUMMARIES

	1945	1946	1947	1948	1949	1950	1951	1952
Year to Date	89.3	101.3	101.3	97.1	87.6	95.9	99.9	90.5
Year Average	85.4	96.9	101.7	92.1	83.7	95.8	98.0	

‡ Preliminary.
r Revised.

PAPERBOARD OPERATING RATIOS†

	Oct. 4	Oct. 11	Oct. 18	Oct. 25	Nov. 1
1952	95	96	97	97	97
	Oct. 6	**Oct. 13**	**Oct. 20**	**Oct. 27**	**Nov. 3**
1951	88	90	89	85	85

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year Avg.
1951	102	105	104	105	104	103	84	94	86	87	82	75	94
1952	81	86	85	82	82	82	71	89	88	96			

All of the above data is based on tonnage reported to American Paper and Pulp Association. Does not include mills reporting to National Paperboard Association, except in isolated cases where both paper and paperboard are produced and separate tonnage figures are not readily available. Does not include mills producing newsprint exclusively.

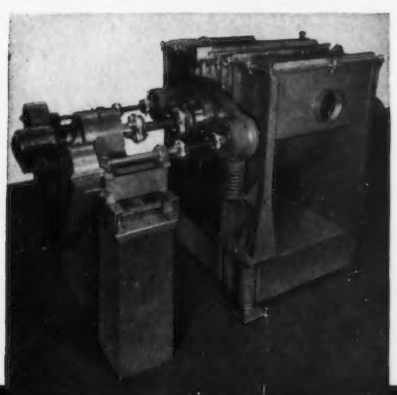
Note: In the above tables *all* the ratios shown are on the basis of a normal 6 and 7 day capacity.

† Per cents of operation based on "Inch-Hours" reported on a 6-day basis to the National Paperboard Association.

BIG VOLUME*
HIGH CONSISTENCY**
SMALL SPACE***
LOW POWER****

ADD UP TO THE

BIRD VIBROTOR SCREEN



Ask us what it can do for you on sulphate or sulphite pulps, on deinked stocks, on heavy weight paper stocks.

*VOLUME? 65 to 150 tons per Screen per day, depending on kind of stock and cut of screenplate

**CONSISTENCY? 1.5 to 2.0% or higher

***SPACE? Less than 65 sq. ft.

****POWER? ⅓ HP or less per ton

BIRD MACHINE COMPANY

SOUTH WALPOLE • MASSACHUSETTS

PRICES

The prices below reflect market quotations in New York at the mill level on standard grades. Does not include spot offerings.

PAPER AND BOARD

Standard News, Delivered Ports

Rolls, contract, per ton	$121.00/$126.00
Sheets	138.00/ 147.50

Kraft—per cwt. 50# base wgt. OPS Ceiling CPR 88

F.o.b. Southern & Western integrated mills. C.l. Freight allowed up to $10 a ton.

Standard Wrapping, ctr. rolls	$7.75/ —
Butchers, counter rolls	8.25/ —
Standard Bag, mill rolls	7.50/ —
Shipping Sack, mill rolls	7.75/ —
Gumming, mill rolls	8.00/ —
Asphalting, mill rolls	7.75/ —
Envelope, Sub. 20, mill rolls	9.25/ —

Tissues—per ream 24x36 (480) 10 lbs. 2500 lbs.

Wh. No. 1 Frd.	$1.85/$1.90
Wh. No. 1 MG	1.85/ 1.90
Wh. No. 1½	1.50/ 1.65
Wh. No. 2	1.35/ 1.45
Kraft Anti-Tar 20-30	1.75/ 1.80
White Anti-Tar 20-30	2.20/ —

Toilet— per case of 100 rolls—1M sheets

Unbleached 4½x4½	$8.00/$8.25
Unbleached 4½x5, 650 sheets	6.65/ —
Bleached 4½x4½	10.00/12.50
Bleached 4½x5	9.81/10.14
Per Case of 50 rolls—2000 sheets	
Unbleached 4½x4½	$8.00/$9.75
Bleached 4½x4½	6.95/ —
Per Case of 100 rolls—1000 sheets	
Facial, 4½x4½, 2 ply	$8.95/10.37
4½x5, 2 ply	10.25/10.75

Paper Towels—per case of 3750

Wh. Jr. M'tif'd 9¼x9½	$6.40
Br. Sr. M'tif'd 9¼x12	4.40
Br. Jr. M'tif'd 9¼x9¼	3.90
Br. Jr. Sgl. fold 9¼x10¼	3.95
C-Fold 10¼ min. x 14 max.	5.90/ 6.64
Blchd. 7½x11, 48/50 rolls	6.80/ 7.92

Manila, per cwt.

No. 1 Jute Tag, 100-lb., sheets	$19.55/21.55
Reg. Jute M.F. 40-lb., sheets	18.50/20.50
Printing Manila	12.00/ —

Gummed Tape—per bdl., 500 bdls. or more

90-lb. 375 ft. GSI	$6.90/ —
60-lb. 600 ft. GSI	6.90/ —
35-lb. 800 ft. GSI	7.95/ —
35-lb. 500 ft. GSO	6.00/ —

MARKET WOOD PULP

Fourth Quarter Contract Prices, Per Short Air-Dry Ton

	Delivered Basis		Varying Freight Allowances		
	U.S.	Canadian	Swedish	Finnish	Norwegian
Groundwood	$82.50/ 87.50†	‡$60.00/ 90.00	$66.00/ 70.00		$75.00/ — §
Sulfate, Bleached	140.00/147.50	145.00/155.00	140.00/142.50§		
Semi-bleached Sulfate	140.00/ — *		135.00/ —		
Sulfate, Unbl.	100.00/ —	100.00/125.00	$100.00/105.00§	$105.00/135.00	100.00/ — §
Sulfite, Blchd.	140.00/ —	140.00/145.00	140.00/ —	140.00/ —	140.00/145.00
Sulfite, Unblchd.	125.00/132.50	135.00/ —	115.00/ — §	120.00/125.00	115.00/ — §
Sulfite, Unbl'd (Glassine)	132.50/ —	139.00/ —	119.00/ — §		
Soda, Blchd.	140.00/ — *			Delivered Basis	
Sulfite Screenings	45.00/ —				
Stand. News, Sideruns	92.50/ — *				

* OPS Ceiling, CPR 49. ‡ F.o.b. Shipping Point. § On Dock Atlantic Ports.
† Midwestern markets.

Boards Deld., per ton (10 tons or over)

Filled News	$90.00/ —
Plain Chip	90.00/ —
Blchd. Mla. L-d. Chip	140.00/142.50
White Pat. coated .020	160.00/162.50
Kr. Liner 42 lb. M sq. ft. $2.47	117.50/ —
Kr. Corr. .009 M sq. ft. $1.59	122.50/ —
Binders Boards	133.00/ —

The following prices are representative distributors' resale prices:

Rag Content Bonds and Ledgers—
White, 20 lb.

Bonds	4-Ctns. per cwt.
100% Rag. Ex. No. 1	$70.45/$75.90
100% Rag	62.65/ —
75% Rag	48.15/ —
50% Rag	38.90/ —
25% Rag	31.65/ 33.00

Ledgers	4 Ctns. per cwt.
100% Rag Ex. No. 1	$72.65/$72.80
100% Rag	63.90/ —
75% Rag	49.40/ —
50% Rag	40.20/ —
25% Rag	33.00/ 34.30

Sulphite Bonds and Ledgers
White, 20 lb.

Bonds	4 Ctns. per cwt.
Watermarked	$19.00/$20.50
Plain	18.40/ 19.50

Ledgers	4 Ctns. per cwt.
Watermarked	$20.30/$21.80
Plain	19.35/ 20.80

White Book

Conversion Coated	Case per cwt.
No. 1	$23.90/$24.65
No. 2	22.40/ 22.85
Machine Coated	
Extra No. 1	$21.35/$21.65
No. 1	19.15/ 19.65
No. 2	16.65/ 17.40
Uncoated	
No. 1 Antique (Watermarked)	$19.15/$19.65
Offset	18.15/ 19.15
A Grade E. F.	18.40/ 18.65
A Grade S. C.	18.90/ 19.15
B Grade E. F.	17.40/ 18.15
B Grade S. C.	17.90/ 18.65

‡ Indicates a price change.

WASTE PAPER MARKET

Prices to mills, per ton, f.o.b. cars shipping point (includes brokers' fee.) These quotations are a partial indication of the price range on volume tonnage in each market on the date specified, as gathered from major dealers. SPECIAL PACKINGS AND SPOT TONNAGE NOT INCLUDED. See TRENDS.

	New York Nov. 10	Philadelphia Nov. 7	Boston Nov. 8	Chicago Nov. 5
No. 1 Mixed Paper	$7.00/ 10.00	$8.00/ 10.00	$7.00/ —	$10.00/ —
No. 1 News	12.00/ 13.00	11.00/ 13.00	12.00/ —	15.00/ —
Over-issue News	20.00/ 22.00	18.00/ 23.00	12.00/ 14.00	18.00/ —
Mill Wrappers	7.00/ 8.00	10.00/ 12.00	13.00/ 19.00	13.00/ —
Corrugated Containers	14.00/ 15.00	12.00/ 15.00	15.00/ 16.00	20.00/ —
Double Kraft Ld. Corr. Cuts	31.00/ 40.00	30.00/ 37.50	25.00/ 40.00	35.00/ 40.00
100% Kraft Corr. Cuts	45.00/ 55.00	40.00/ 50.00	35.00/ 45.00	50.00/ —
Used Sugar & Flour Bags	35.00/ 45.00	27.50/ 35.00	25.00/ 35.00	30.00/ —
Triple Resorted Br. Kraft	40.00/ 45.00	25.00/ 35.00	20.00/ 35.00	30.00/ —
New Br. Kraft Env. Cuts	65.00/ 70.00	55.00/ 65.00	55.00/ 65.00	50.00/ —
New Br. Kraft Bag Cuts	55.00/ 60.00	45.00/ 60.00	45.00/ 55.00	50.00/ —
No. 1 Gdwd. Shvs.	20.00/ 30.00	15.00/ 17.50	28.00/ 30.00	25.00/ —
White Newsblanks	65.00/ 70.00	60.00/ 75.00	40.00/ 50.00	50.00/ —
No. 1 Flyleaf Shvs.	30.00/ 35.00	30.00/ 40.00	25.00/ 42.50	30.00/ —
No. 1 Soft Wht. Shvs.	75.00/ 85.00	55.00/ 75.00	75.00/ 85.00	75.00/ —
Super Soft Wht. Shvs.	85.00/ 95.00	65.00/ 75.00	95.00/100.00	85.00/ —
Hd. Wht. Shvs.	95.00/100.00	85.00/ 95.00	85.00/100.00	90.00/ —
Hd. Wht. Env. Cuts	115.00/125.00	95.00/120.00	105.00/120.00	100.00/ —
New Manila Env. Cuts	65.00/ 72.00	60.00/ 80.00	75.00/ 85.00	40.00/ —
Col. Tab. Cards	55.00/ 60.00	47.50/ 55.00	40.00/ 50.00	50.00/ —
Manila Tab. Cards	70.00/ 80.00	70.00/ 80.00	75.00/ 85.00	60.00/ —
No. 1 Mixed Ledger	40.00/ 47.50	35.00/45.00	35.00/ 45.00	50.00/ —
White Ledger	52.50/ 57.50	50.00/ 60.00	55.00/ 60.00	65.00/ —
No. 1 Book & Mag.†	16.00/ 18.00	}	18.00/ 28.00	15.00/ —
No. 1 Rep'd. Hvy. Books‡	26.00/ 35.00	}no market	30.00/ 37.50	27.50/ —

† Includes Time & Life; no coarse groundwood. ‡ Not to exceed 10% groundwood. § Deld.

RAG MARKET

New Domestic Cotton Cuttings
Delivered Mill Basis

No. 1 White Shirts	$15.00/$15.50
No. 1 Unblchd. Muslins	17.00/ 17.50
Blchd. & Unblchd. Underwears	16.00/ 16.50
Blchd. Canton Flannels	15.00/ 15.50
No. 1 Light Silesias	13.00/ 13.25
No. 1 Light Prints	8.50/ 8.75
No. 1 Blue Overalls	11.00/ 11.75
Suntan Khakis	8.00/ 8.50
Fancy Shirts	7.50/ 7.75
Indigo Blues	7.25/ 7.50
Mixed Khakis	5.50/ 6.00
Corduroys	6.00/ 7.00
Cottonades	6.00/ 6.50
No. 1 Washables	5.00/ 5.25

Old Domestic Cotton Rags
(Prices to Dealers, F.o.b. Ship. Pt.)

	Per 100 lbs.
Mixed White	$3.50/$4.50
Cotton Pants & Overalls	3.00/ 4.00
Thirds and Blues, Repacked	2.50/ 3.00
No. 1 Roofing Rags	1.30/ 1.40
No. 2 Roofing Rags	.90/ 1.00

Bagging
(Prices to Dealers, F.o.b. N. Y.)

	Per 100 lbs.
Foreign Gunny	$5.00/$5.25
Heavy Wool Tares	5.00/ 5.50
Foreign Scrap Burlap	4.50/ 4.75
Austr. Wool Pouches	6.00/ 7.00
Domestic Manila Rope	6.50/ 7.00
No. 1 Sisal Strings	6.00/ 6.50

COTTON LINTERS

Memphis Market
F.o.b. Oilmills

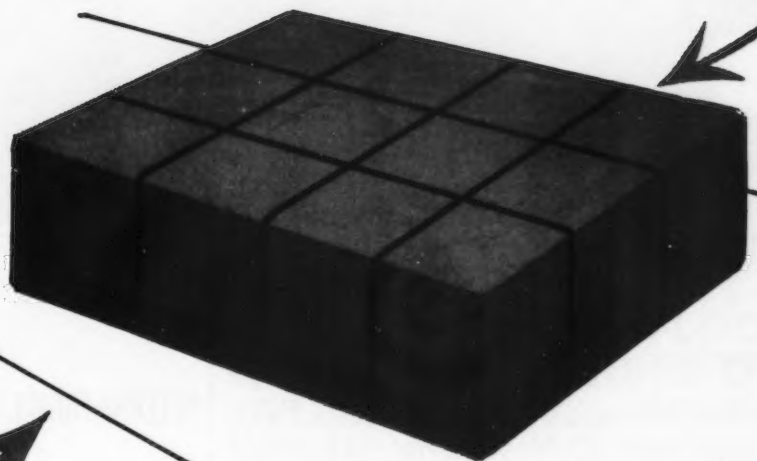
	Nov. 5 cents per lb.
Grade 2	13.25/ 12.00
3 1st cut	11.50/ 10.00
4	9.00/ 6.50
5	6.00/ 4.50
6 2nd cut	4.00/ 3.75
7	3.75/ 3.50

Lyddon & Co.

exporters of wood pulp
to all world markets

Parsons & Whittemore

paper exporters
wood pulp



London

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Buenos Aires Sao Paulo

10 East 40th Street, New York 16, N. Y.

RESTIGOUCHE

BLEACHED SULPHITE PULP

for the manufacture of Cellophane, Rayon and Products of Paper

Restigouche
BLEACHED SULPHITE PULP

RESTIGOUCHE COMPANY, LTD.

Campbellton, N. B., Canada

PRICES OF MATERIALS

Aluminum sulfate:		
coml. bags, wks.	cwt.	1.65
iron-free. c.l.		3.25
Alcohol, ethyl:		
tax free, dms. c.l.	gal.	1.01 / 1.05½
deld. East Miss.		
Alcohol, methyl:		
Synthetic, Zone 1, dms. c.l. ft. alld.	gal.	.44
Casein, acid prec.:		
dom. sh. pt. c.l.	lb.	.28 / .38
imp. ex. dock	lb.	.20½/ .24
Caustic soda:		
c.l. wks. solid, 76%	cwt.	3.35
flak. & grd. 100-lb. drums		3.75
liquid 50% tanks		2.55
liquid 70% tanks		2.65
China clay:		
dom. air-float, c.l. wks.	ton	10.00
water-washed, lump, filler		11.00
coating		17.60 /30.50
imported, ex. whse.	short ton	15.20 /28.35
Chlorine:		
single-unit tanks, works	cwt.	2.70
multi-unit	cwt.	3.20 / 4.40
Formaldehyde:		
USP, inh. dms, c.l. wks.	lb.	.0625/ .0675
l.c.l., E. wks.		.0675/ .0725
Fuel oil:		
Bunker C, No. 6 hvy. tanks, N.Y. harbor	bbl.	2.10 / —
light, tanks, refinery	bbl.	2.00 / 2.25
Hydrogen peroxide:		
USP, 35% cbys. E. of Miss.	lb.	.23½/ .26½
Lime:		
hydrated, bags, wks.	tons	13.50
Rosin:		
B gum, drms, c.l. Savan.	cwt.	7.00 / —
K, M, N	cwt.	7.33 / 7.40
FF, wood, do.	cwt.	4.10 / 6.50
Rosin size:		
70%, gum & pale grds, tank cars, south, sh. pt.	cwt.	6.25 / 6.30
Salt cake:		
dom. bulk, c.l. wks.	ton	17.00
wks. frt. all.	ton	20.00 /22.00
Soda ash:		
light, 58%, bags, wks.		1.50
bulk	cwt.	1 20
Sodium silicate, 40°:		
turbid. c.l. wks.	cwt.	1.30 /
l.c.l. wks.		1.60 / 1.85
Sodium peroxide:		
dms. c.l. E. of Miss.	lb.	.21
l.c.l. do.	lb.	.21½/ .22
Soybean, protein:		
chem. isol, wks, c.l., bags.	lb.	.23½/ .24¼
Sulfuric acid:		
60° Be cbys. c.l. wks.	cwt.	1.75 / —
l.c.l. wks.	cwt.	2.05 / 2.85
Sulfur:		
crude, c.l. mines, contract,	long ton	21.00 /22.00
f.o.b. vessels Gulf		22.50 /23.50
Sulfur dioxide:		
liquid, coml. cyl. wks.	lb.	.09
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white, dextrines, c.l. wks.	cwt.	7.78 / —
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potato, Maine, f.o.b. wks.	cwt.	10.50 /11.00
potato, imported O.D.	bags	8.60 / 8.90
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domestic, sacks, c.l. wks.	ton	25.00 /30.00
Titanium dioxide:		
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l.c.l. deld.	lb.	.22 / .22½
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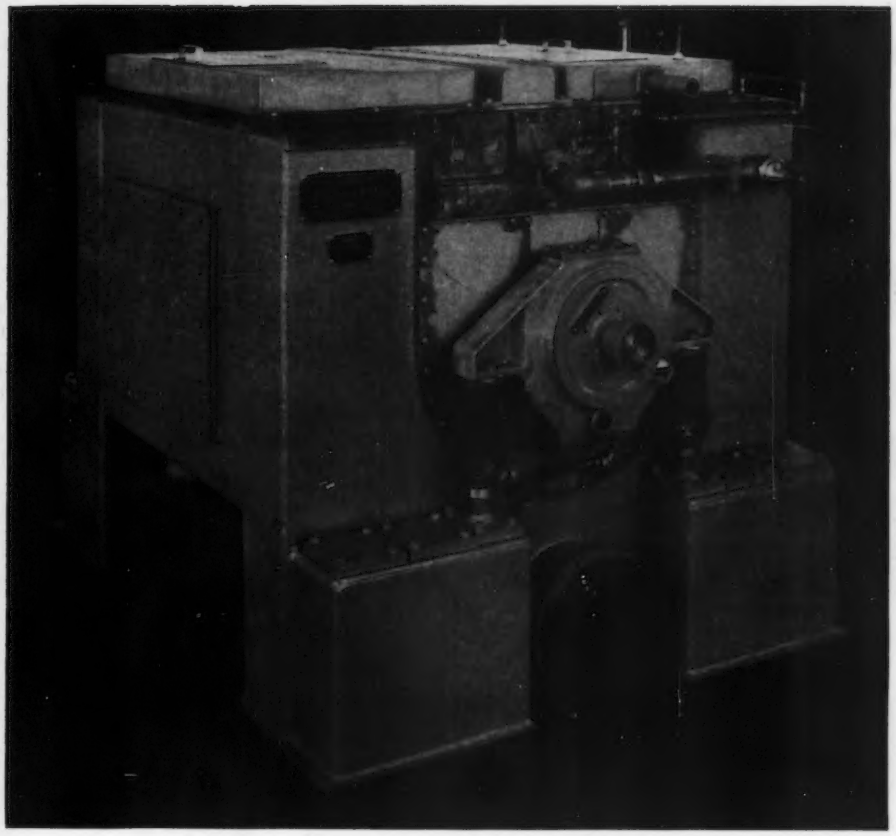

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Acknowledgements

I am glad for this opportunity to express our appreciation to those men who have come to our campus to lecture to students in the pulp and paper course, and to the companies they represent. The paper industry has cooperated wholeheartedly.

This volume is graphic witness to the way in which we have been able to give substance to the course, through those who have had daily, practical experience in the paper making field.

We are grateful to the publishers and to Mr. Henry J. Perry, the editor, for this chance to bring these lectures to a wider circle of readers by publication in the PAPER TRADE JOURNAL.

Orono, Maine
October 3, 1952

Arthur A. Hauck

ARTHUR A. HAUCK, *President*
University of Maine

J. L. Ober

All of these papers were prepared for The Pulp and Paper Course at The University of Maine. They were edited by L. C. Jenness and John Lewis and published by agreement with The Department of Industrial Cooperation at The University of Maine.

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L. C. Jennoss

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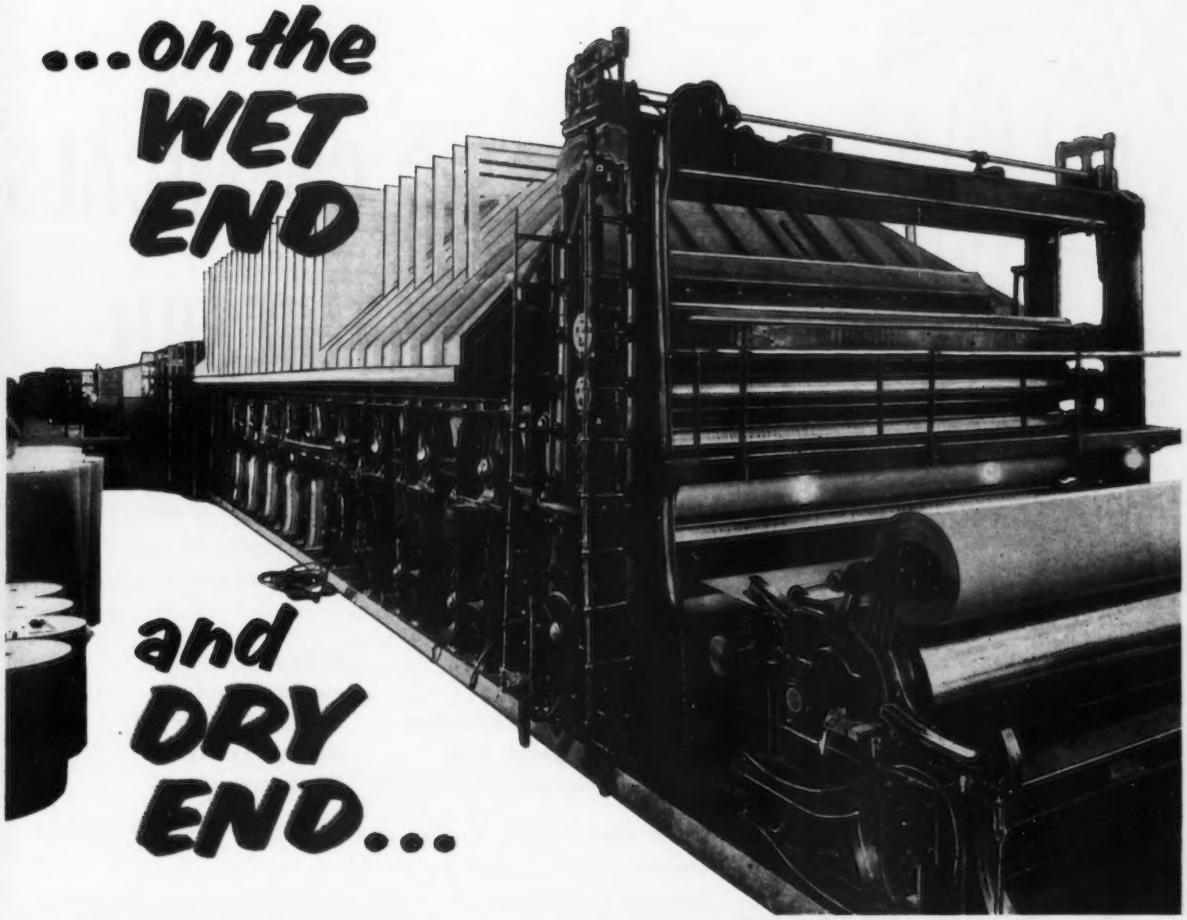

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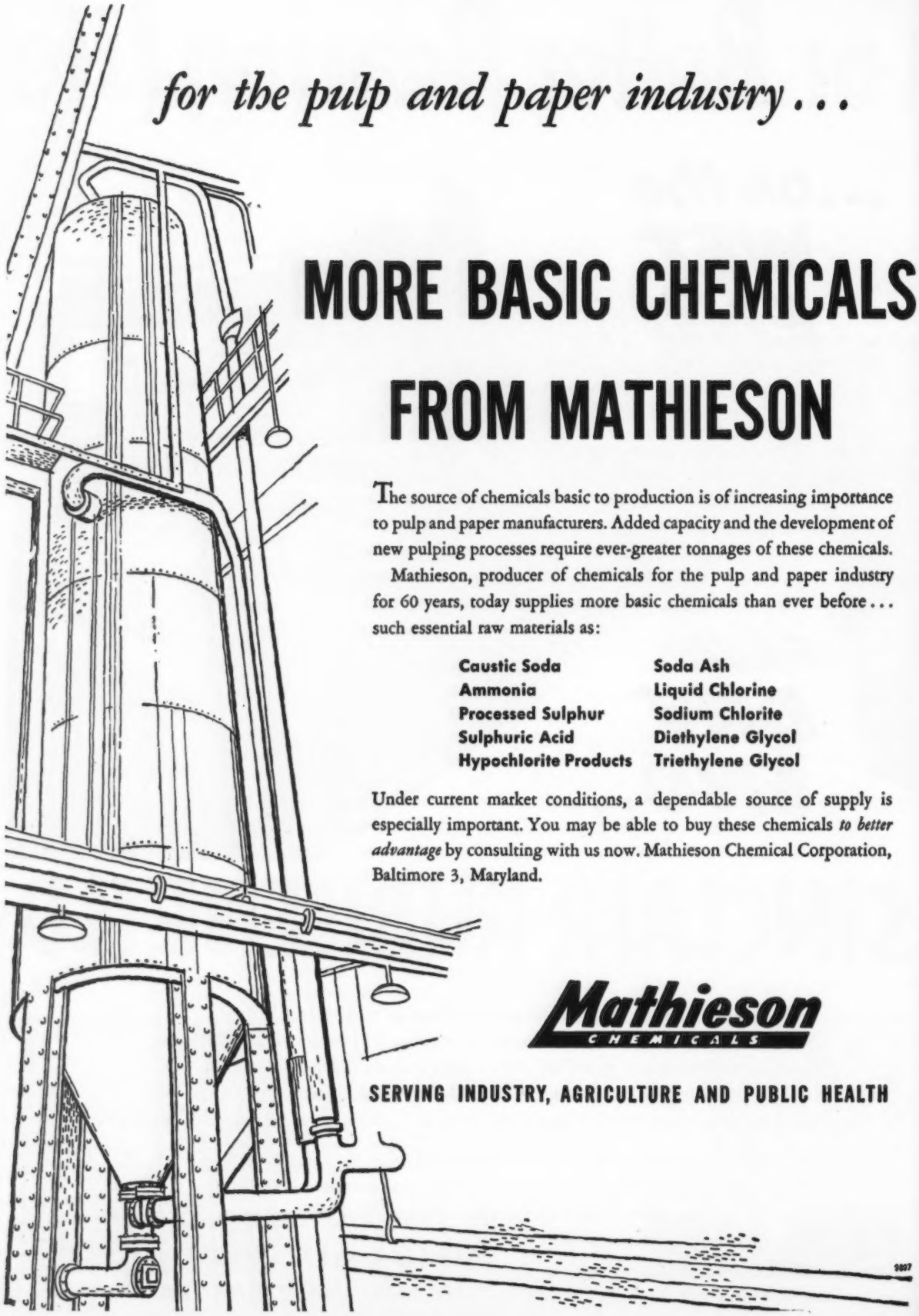

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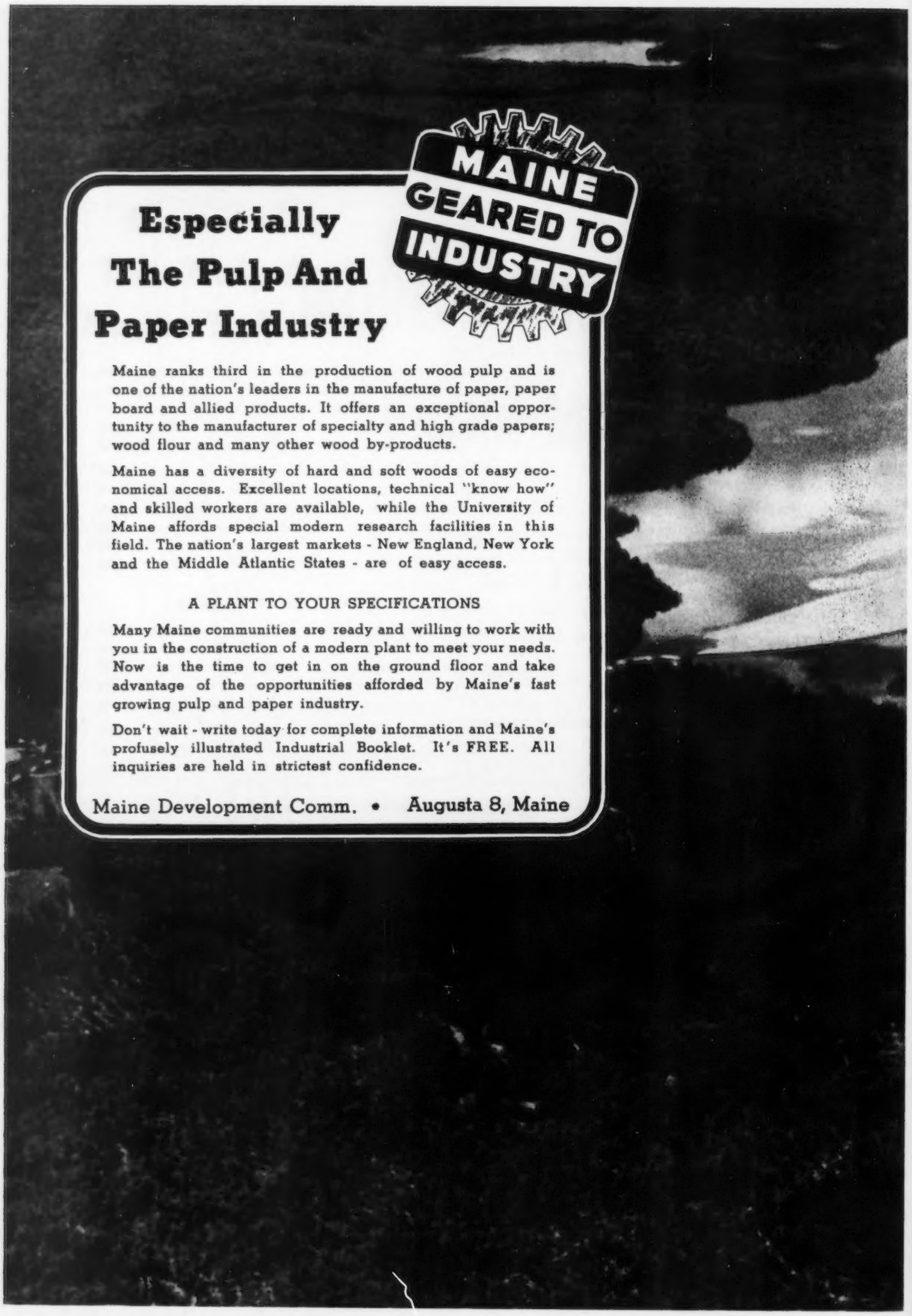
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The Structure of Wood

Professor Fay Hyland[1]

Graduate, Michigan State College, B.S.; University of Maine, M.S.; Graduate Work, Harvard University. Professor of Botany, Dept. of Botany and Entomology, University of Maine, Orono, Maine. Professor Hyland is author of many papers and is an authority on the woody plants of Maine.

The Growing Points

By way of brief introduction to a discussion of wood structure proper, it may be necessary to consider a few fundamentals on plant growth which are often not well understood by the layman. Plants, as well as animals, are composed of numerous structural units called cells. It is by the increase in number of sizes of these cells that growth is accomplished. In trees, such as those commonly used for pulp, two distinct regions of growth or cell division, may be recognized:

1. Apical Zone. (Figure 1) This zone is located at the tips of the stems and roots. In stems it is enclosed within the buds during the dormant period. During the growing season it consists of one or more groups of actively dividing cells resulting in elongation of the tips of these organs. The cells may divide along several planes simultaneously, thus accounting for the broad, rounded tips of such stout twigs as ash and walnut. Not only is all length growth of the tree due to the activity of this growth region but the formation of all appendages (buds, leaves, branches, fruits, etc.,) as well.

2. Cambial Zone. (Figures 1 and 2) This zone, in contrast to the apical zone, forms a thin cylinder or sheath of cells located between the wood and the inner bark ensheathing the trunk, limbs, and roots. It extends nearly to the tips of these organs. Strictly speaking, the cambium as such is a layer, one cell in width, which divides tangentially to form the diameter growth of stems and roots. Occasional radial division of the cells increases the girth of this layer. A small amount of the early diameter growth of stems and roots is derived from a tissue called the primary meristem which is a product of the apical zone of cells. It consists essentially of the pith, primary wood and bark, pericycle, endodermis, cortex, and epidermis. Most of these tissues outside the pith will be replaced at an early date by growth layers formed from the cambium and, since an understanding of them is not essential for the purpose of this article, they will not be further discussed here. During the growing season the cambium is very active and forms cells in such rapid succession that it appears as a zone instead of a narrow layer and hence is often referred to by the former term. The cambial zone is, in reality, the cambium proper (a delicate, soft layer), plus a number of newly formed cells that have not had time to mature into the firm cells of wood and bark which they are destined to become.

[1] Botany Department, University of Maine, Orono, Maine.

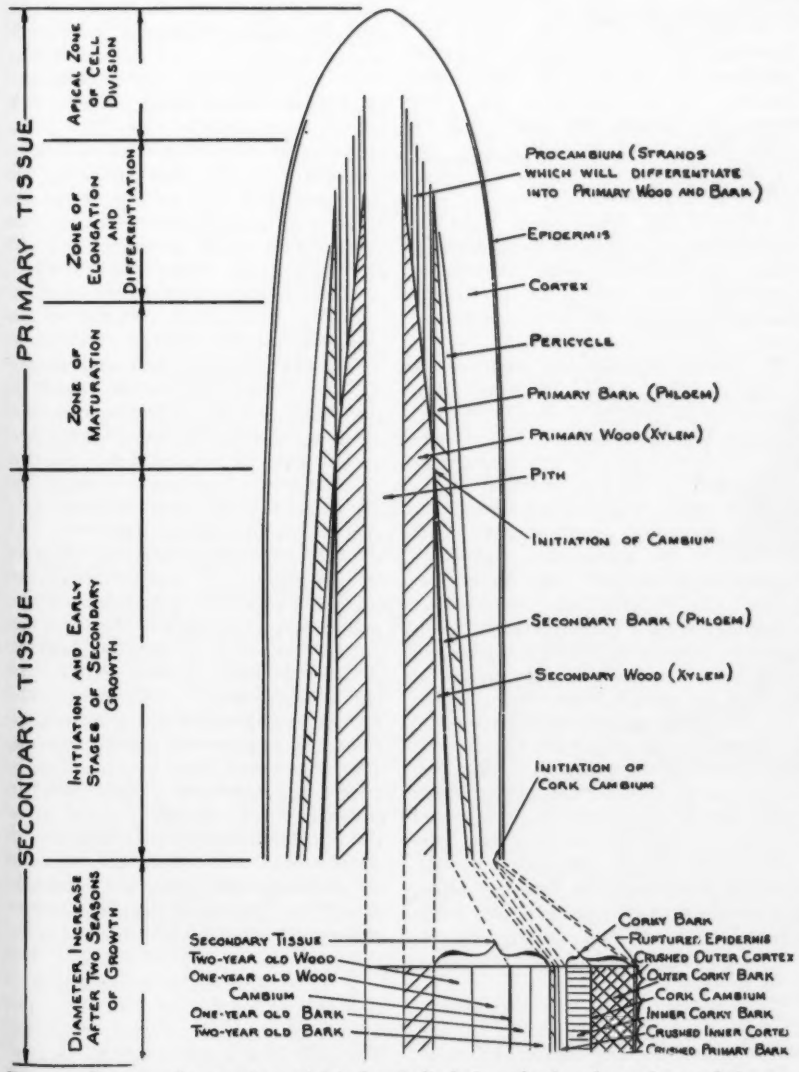

Figure 1—Diagram of a growing point in longitudinal view, showing the regions and tissues at progressive stages of development.

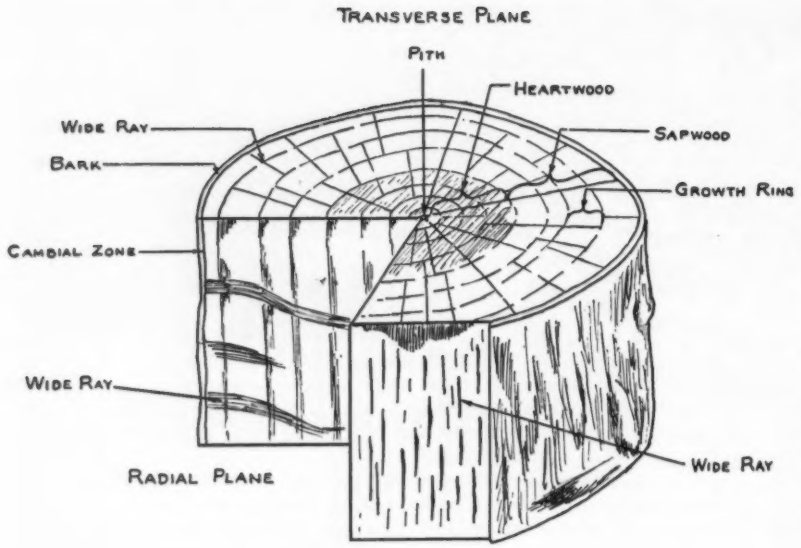

Figure 2—Diagram of an oak block, showing the gross features.

Anyone who has made a whistle from a poplar branch, or stripped the bark from a slippery elm in order to obtain the gelatinous layer beneath, is aware of these soft cells. Woodsmen know that pulp bolts will peel more freely if the peeling operation is carried out on trees cut during or shortly following cambial activity early in the season. At that time there is a rather wide zone of immature soft cells which may be easily crushed, thus allowing the bark to separate freely from the wood. Foresters are now treating standing trees with chemicals during the months of May and June, to facilitate peeling of pulpwood. Trees thus chemically treated may, after a delay of four or five months, be peeled at almost any time of year. (See *Journ. For.* 48: 519. 1950)

The cells composing the cambium are as varied in shape and size as those derived from it. That is, some are squarish or brick shaped while others are spindle shaped. The squarish cells may develop into rays while the spindle shaped cells become fibers, vessel elements, and similar elongate types of cells. In length, the elongate cambium cells (initials) range from approximately 0.2 to 5 millimeters. They range from less than twice to more than 100 times longer than they are broad.

The two growth zones discussed above are active, periodically, throughout the life of the tree. The apical portion continues the seasonal elongation of the stems, with their appendages, and the roots. The seasonal activity of the cambium adds periodically to the diameter of the stems and roots, resulting eventually in the massive trees with which we are all familiar. During the course of tissue development many cell types are formed. These, especially the ones important in pulp and paper, will be discussed in some detail later.

Organs and Tissues

Mention has already been made of certain organs and appendages formed from the growing points. It will be appropriate at this point to briefly consider certain of these, especially with regard to their function:

1. Leaves. These are the organs which synthesize food by means of a complicated process called photosynthesis. The essentials of the process are: Chlorophyll (the green pigment contained in leaves), sunlight, a favorable temperature, carbon dioxide (a gas composing approximately 0.03 percent of the atmosphere, and water (containing essential soil nutrients). These raw materials are converted by the leaves into carbohydrates (compounds containing carbon, hydrogen, and oxygen) which are the foods essential for energy and growth. These foods (simple sugars, which are water-soluble carbohydrates) are transported by means of the inner bark from the leaves to all parts of the plants where they are needed. Some food is stored as starch, which is an insoluble carbohydrate. These storage materials, as well as certain oils, fats, and nitrogen-containing compounds, are often found in wood and usually are removed in the standard chemical pulping processes.

2. Roots. These are the subterranean anchorage, supportive, storage, and water-absorbing organs of the tree. The essential elements such as calcium, phosphorus, nitrogen, sulphur, iron, and magnesium enter the water-conducting system by way of the roots. These elements, along with carbon, hydrogen, and oxygen, are the raw materials necessary for synthesis of food and ultimate growth.

3. Stems. Figure 2 shows an oak block which has been cut in such a manner that the three planes (transverse, radial, and tangential) are clearly visible. It will be seen that each plane is at right angles to the other two. The transverse plane shows the vertically elongate cells in end view and the wood rays in top view. The growth rings and also the heartwood and sapwood are most easily distinguished in this plane of section. The radial plane shows the radial side of the vertically elongate cells and the sides of the wood rays, which appear as patches. Radially cut (or quarter-sawn) lumber is often highly prized because of the pleasing effect produced by the wide wood rays. The tangential plane shows the wood as it would appear if it were slab sawn. The wood rays are less conspicuous than in the radial plane because they are viewed from the ends. This plane is useful in measuring the true height and width of the rays and also for determining the ray volume of woods. It may be necessary to refer to this sketch occasionally in order to avoid confusion of these planes when reference is made to them in this article.

Figure 3 shows a portion of the cross section of a large tree trunk. The outer bark is thick and deeply fissured in contrast to that shown in the young oak stem. The enlargement of a portion of the wood shows the growth ring in somewhat more detail, or as it would look under a magnifying lens. The functions of stems are: (a) Conduction of food and raw materials, (b) storage, and (c) support of branches with their display of leaves. From the standpoint of the pulp industry the stem is the most important organ of the tree and will be considered here in some detail. As has been mentioned earlier, the structure of very young stems is complicated by the presence of primary tissues. But, since all of these primary tissues except the pith and a thin zone of primary wood, disappear soon after the cambium begins to function, a discussion of this early growth may be dispensed with here, and emphasis placed on the more significant secondary growth, which is derived from the cambium.

a. Pith. A cross or transverse section of a sound log or trunk of a tree usually shows several gross features. The pith is a small, centrally located area of soft food-storage cells. In diameter it usually varies from the

size of a common pin to that of a lead pencil. It is never larger in the trunk than in the twig of the tree. The large "pith cavities" commonly referred to in old trees are actually cavities formed by rotted heartwood in addition to the pith.

b. Wood. (Figures 2, 3, 4, and 5) Surrounding the pith are several to many concentric growth rings of wood which were formed by the cambium. Each ring is composed of an inner, porous zone called the earlywood or spring wood, and an outer, denser zone called the latewood or summer wood. The earlywood is composed chiefly of water-conducting cells, while the latewood contains numerous fibers or fiber-like cells whose principal function is support.

Often an inner zone of heartwood may be distinguished from the outer zone of sapwood which lies next to the cambium. Once heartwood formation has begun, layers are added periodically by the transformation of the inner-most portions of the sapwood until, ultimately it constitutes the bulk of the wood. The heartwood is often darker in color than the sapwood because of infiltrated substances, including tanins, resins, etc. All cells of this region are dead and function only as support. Often the water-conducting tubes (vessels) are clogged completely by outgrowths of neighboring soft cells which have forced their way in through tiny holes (pits) in the side walls of the vessels. Certain fungous growths often destroy the heartwood of trees but will not invade the sapwood. These "hollow" trees may live on indefinitely showing little ill effect due to the loss of the central core.

The sapwood is often lighter in color than the heartwood, although often the line of demarcation between the two zones is not distinct. It varies from a few to many rings in width. This is the water-conducting region of the tree. It should be emphasized that the vessels and other water-conducting cells, as well as the fibers and similar supporting cells, are dead even though the sapwood is said to be living. It is only the soft cells (parenchyma), contained in the sapwood, that are living. Never-the-less, these minute water-conducting elements of capillary size succeed in transporting water from the roots to the tips of the tallest trees.

Wood Rays. The continuity of the rings is interrupted at short intervals by straight lines radiating from the pith toward the cambium, much as the spokes of a wheel radiate from the hub. These are wood rays. Actually the rays are vertically disposed sheets or plates of cells arranged much as bricks in a wall. They appear as lines because in the cross section of a stem they are viewed from above much as one would view a brick wall from above. The radial view of the wood block will show them to better advantage. Rays serve to conduct food laterally in the stem and also store food. Those in the sapwood are living but those in the heartwood are dead. Only a small number of rays actually originate in the pith, and these are the only ones which should be correctly termed medullary rays. The remainder, which are numerous and sometimes rather conspicuous in such woods as oak and maple, are true wood or vascular rays. They originate in the cambium as do the fibers, vessels, and other wood cells to be discussed later. The wood rays of softwoods and many hardwoods are difficult or impossible to discern with the unaided eye, either because they are too narrow (only one or a few cells wide), or because they are the same color as the other wood cells. Softwoods (conifers or evergreens) include such woods as pine, spruce, fir, cedar, etc. The leaves are needle-like or scale-like and persist for more than one year except in tamarack and baldcypress. The wood lacks vessels and is rather uniform in structure. However, the term "softwood" is misleading because certain woods (the hard pines for example) are very dense and hard. The hardwoods (broad-leaved trees), in contrast, usually shed their leaves at the end of the growing season. The leaves are mostly broad and flat as illustrated by birch, poplar, and oak. Vessels are present in the wood as well as numerous fibers and often wide rays which accounts for less uniformity in structure than in softwoods. Basswood and poplar are "hardwoods" in which the wood is very soft.

Wood Parenchyma. Most hardwoods and some softwoods contain vertically arranged chains of living soft cells in the wood, whose function is food storage and vertical conduction. These parenchyma cells are difficult to see without a magnifier but they can often

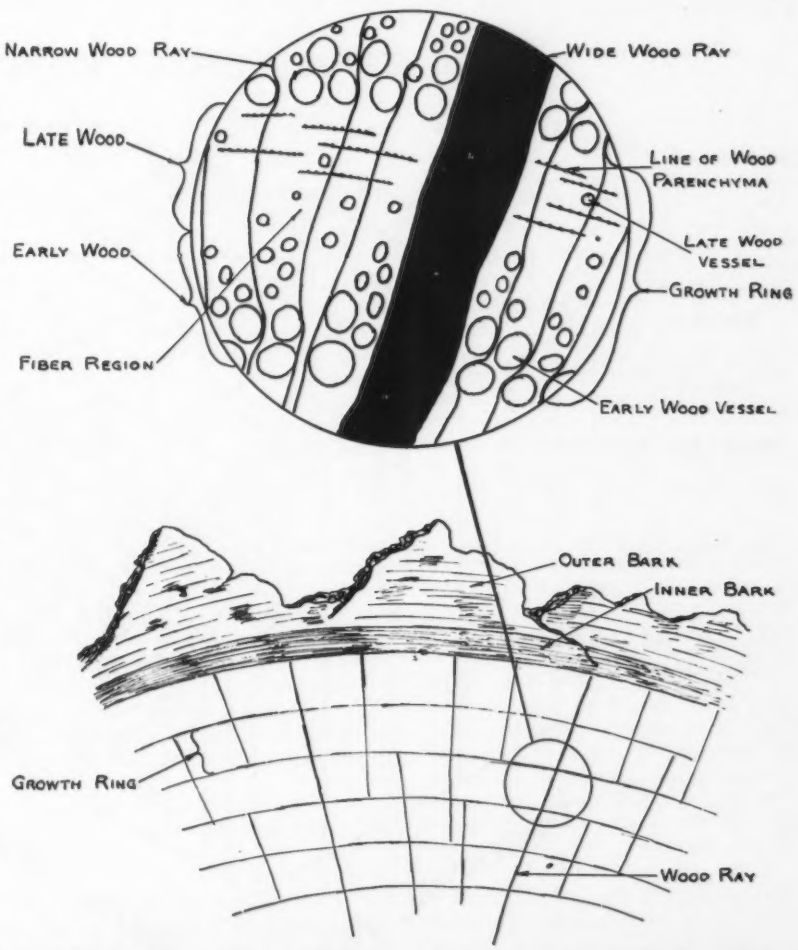

Figure 3—Below, diagram of a portion of an oak log in cross section, showing the gross features. Above, A Portion of the wood enlarged, showing a growth ring in somewhat more detail.

be observed as fine white lines or dots on a clean cut cross section of such woods as oak or birch.

Resin Ducts. (Figure 4) The wood of certain softwoods, for example, pine, spruce, tamarack, and douglas-fir, contains both vertical and horizontal resin ducts or canals. These cavities, which are a constant feature of the wood, are surrounded by resin-secreting parenchyma cells. The vertical canals occur scattered or tangentially arranged among the water-conducting cells, (occupying approximately 1 percent of the wood by volume in pine) while the horizontal ducts, which occasionally connect with those of the vertical system are found only in the rays. Traumatic resin ducts are those formed as a result of injury. They occur sporadically in softwoods, even in such woods as balsam fir and hemlock which usually lack resin ducts. In most cases they are not found in rays. The resin or pitch contained in resin canals of soft woods is an objectionable feature in wood pulp and, when present in significant amounts as in the pines, may render the wood unsuitable for use in certain types of pulping processes.

c. Inner Bark or Phloem. The inner bark is a food-conductive and protective tissue. It is formed by the cambium and lies external to it. The bark of a tree is composed of two distinct regions differing in origin and function.

The inner, softer portion, which originates in the cambium and is composed largely of living cells, is the inner bark, or secondary phloem. It is a complex tissue composed of several cell types, but since this portion of the tree is not used in pulp a further discussion of the cell types will be omitted. Suffice it to say that the inner bark is the tissue which conducts the food, which is manufactured in the leaves, to all other parts of the plant. Since it often contains fibrous or hard cells in addition to the conductive tissue it serves the purpose of protection and support as well.

d. Outer Bark. The outermost layer of bark of the trunk is the cork bark which functions as a protective layer. It develops from the cork cambium, which is a more or less tangentially arranged layer of living cells located in the outer portion of the inner bark. In young stems and roots, the first cork cambium usually develops in the primary tissue (i.e., epidermis, cortex, or pericycle, *Figure 1),* but exentually as the stem increases in diameter due to the activity of the vascular cambium within, these early-formed cambium layers are ruptured and weathered away, being replaced by those formed successively deeper in the inner bark. In trees with rough bark, the outer bark and cork cambium are ruptured at intervals due to diameter increase of the wood and bark beneath. However, new layers are readily formed successively deeper in the stem from parenchyma cells of the inner bark. In certain trees with smooth or layered bark such as beech and paper birch, the original cork cambium may persist indefinitely, increasing in circumference by occasional radial cell division as does the vascular cambium. The cork bark divides tangentially to form cells on both sides as does the vascular

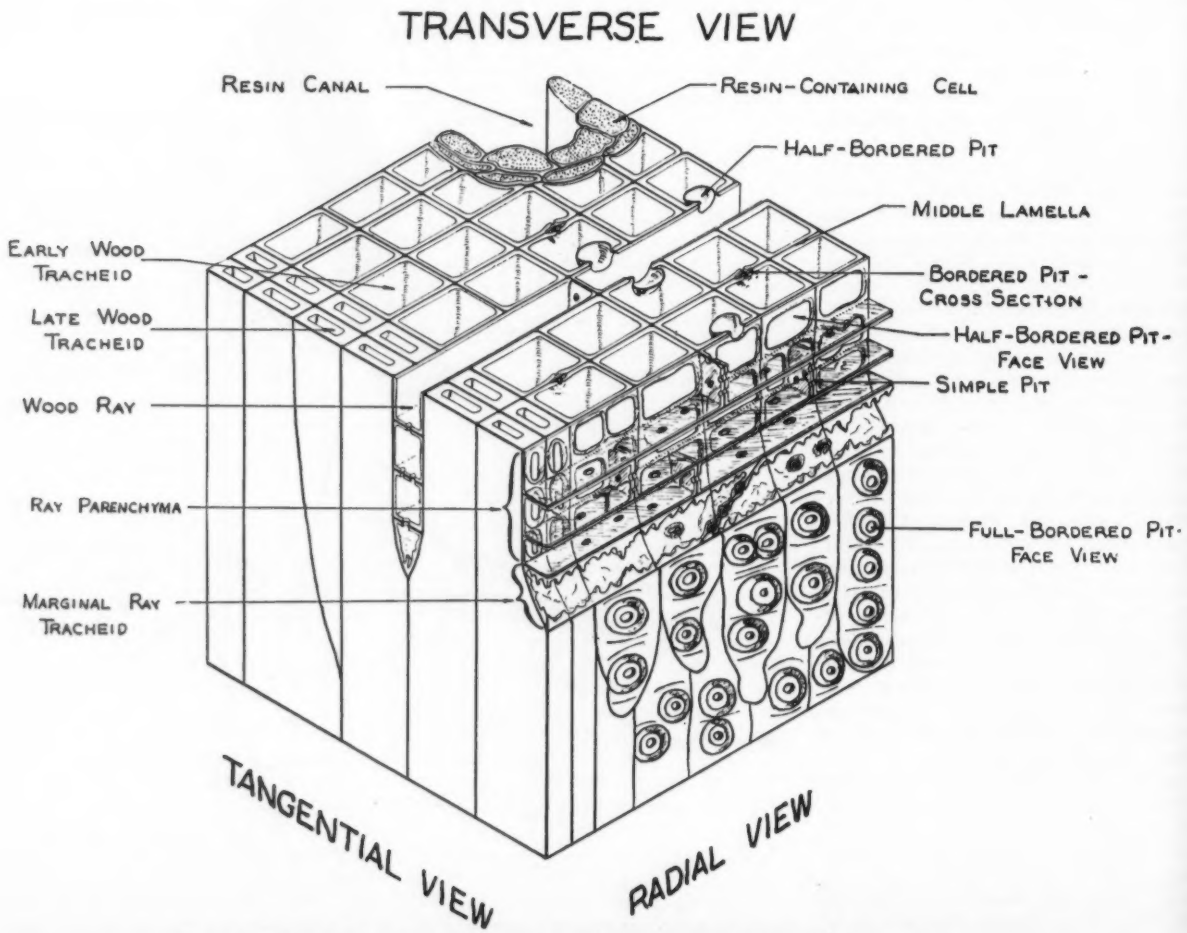

Figure 4—Schematic drawing of a softwood (pine) block, showing structural features in three planes.

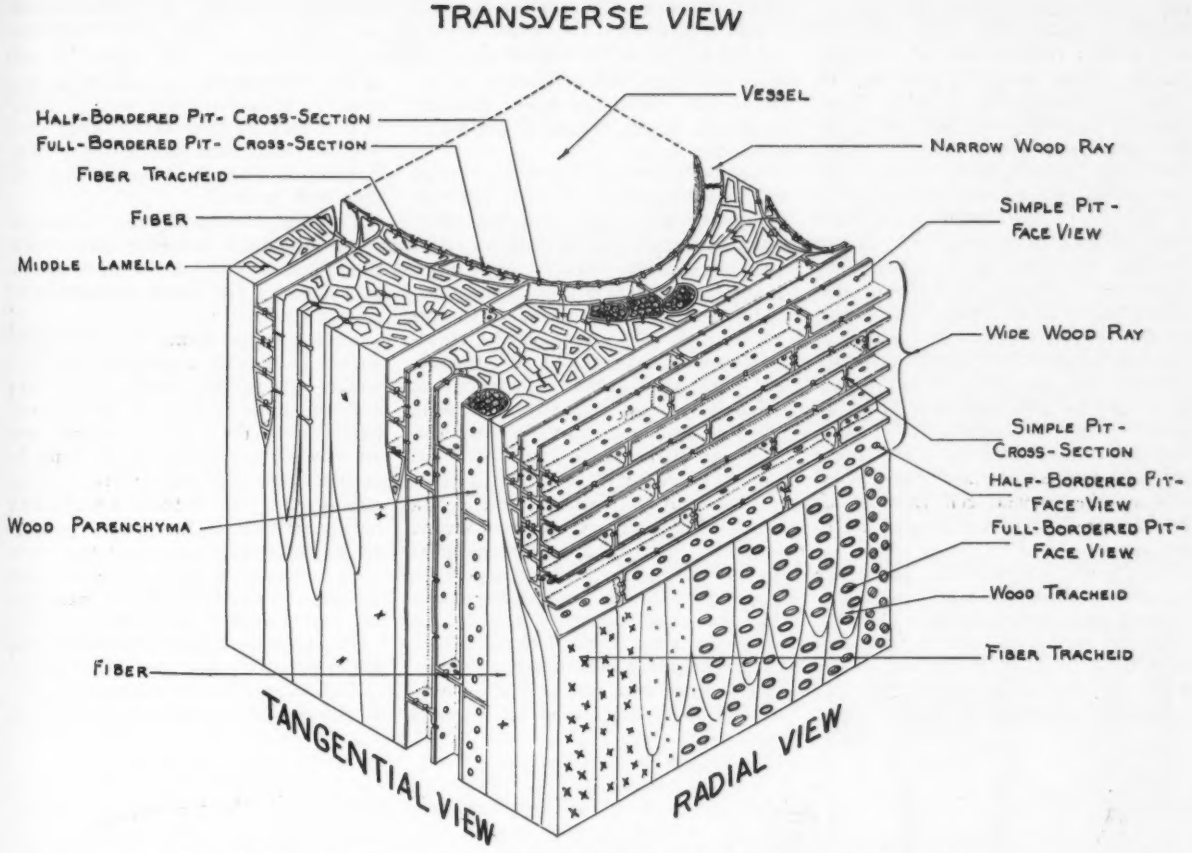

Figure 5—Schematic drawing of a hardwood (oak) block, showing structural features in three planes.

cambium, but instead of forming vascular tissue, it develops rows of arcs of cork cells on the outside and rows of closely fitting parenchyma cells on the inside. The efficiency of cork as a protective layer in guarding against damage due to desiccation, sudden temperature change, mechanical injury, and entrance of certain insect pests and fungous diseases, is due in great part to the thick-walled cells which are infiltrated with fatty or waxy substances. The resistant corky bark of such trees as birch can be found in the forest long after the wood has rotted and disappeared. Not all of the outer, dead bark of a tree is cork derived from the cord cambium. Much of it, especially in rough-barked trees, contains more or less early-formed tissue of the inner bark, or phloem.

The Minute Structure of Wood

The gross structure of wood has been discussed in a general way in the preceding pages. Let us now consider in more detail the elements which are important in paper-making. Reference to the schematic drawings *(Figures 4 and 5)* will show that woods vary greatly in structure.

Types of Cells

1. Tracheids. Figure 4 shows the cell types and arrangements found in a typical softwood, such as pine. It will be seen that tracheids, which are the water-conducting and supporting cells of this tree, form the bulk of the wood (90 to 95 percent by volume). These cells, which are often incorrectly termed "fibers" by the layman, are the important paper-making cells of softwoods. They may also be found in hardwoods, being more numerous in the vicinity of other water-conducting cells.

Tracheids *(Figure 6) typically* possess the following characteristics: (a) great length, (b) small cross sectional area, (c) angularity of outline, (d) thin to medium thick walls, (e) constant width of walls in cross section, and (f) the absence of a distinct end wall.

A central cavity (lumen) occupies the space inside the cell wall. The diameter of this central cavity is greater in earlywood than in latewood cells and is usually several times wider than the cell wall is thick. This is in contrast to fibers (characterized later in this article) which have very small central cavities. The ends of tracheids are rounded or somewhat lobed on the radial side but are mostly chisel-like in tangential view.

There are no openings (pores) at the ends of tracheids as there are in vessels but there are large, rather complicated structures called bordered pits in the side (radial) walls, especially in the overlapping portions near the ends of the cells. These pits possess porous or permeable membranes which allow water to pass through them when the tori (non-porous thickenings) are in a central position, but inhibit the passage of water when in a lateral position, thus closing the mouths of the pits *(Figure 7)*. In heartwood the pit mouths are usually closed and these non-functional pits are said to be aspirated. The water used by softwoods must travel vertically through the sapwood by means of a zigzag course laterally from tracheid to tracheid. It is a primitive and perhaps less efficient method than that possessed by the vessel, to be described later.

Tracheids are exceedingly long cells, commonly measuring 3.0 to 4.5 millimeters, their length often exceeding their width by more than 100 to 1. The value of tracheids in paper-mak-

ing is due in great part to the extreme length of these cells. The tracheids in a mature tree are not all the same length. Those near the pith may be 1 or 2 millimeters long, while those near the cambium and high up in the tree may be 4 or 5 millimeters long. The cross section areas of tracheids also become greater in the outer layers of the stem. The length of cambial cells (initials, or mother cells) is not constant but increases slightly with age, thus accounting for greater tracheid length in old trees. The length of any given tracheid is dependent upon the length of the cambium mother cell and the elongation it has undergone during differentiation. For all types of cells except fibers and fiber-like cells (fiber tracheids) the length of the mature cell does not exceed that of the cambial cell from which it originated by more than 5 to 10 percent.

2. *Vessels (Figure 5).* These are water-conducting tubes of a more specialized type than tracheids. They are found in nearly all hardwoods and in one small group of evergreens. (The wood of one small group of evergreens, the Gnetales, contains vessels, and a few primitive families of hardwoods lack them.) The term "vessel" is here applied to the vertical series of united cells and not to a single cell of the series, which is more properly termed a vessel "element" or vessel segment.

Vessel elements *(Figure 6)* possess the following characteristics: (a) vertically elongate cells varying from drum or keg shaped to elongate tubes, (b) large cross sectional area, with a large central cavity or lumen, (c) angular or circular outline, (d) medium to thick walls, often varying greatly between earlywood and latewood, (e) end wall (either transverse or oblique) distinct from the side wall.

In the development of the vessel elements from the cambial cells, the end walls are eventually wholly or partially dissolved out, forming in effect, a long hollow tube. Water can ascend vertically in a direct line in contrast to the indirect course necessary in tracheids. Vessels are often more numerous and larger in size in the earlywood than in the latewood. This is especially true in ring-porous woods, such as oak and ash. (The opening seen in the cross section of a vessel is known as a pore. Where the vessels are larger in size or more numerous in the earlywood, the wood is said to be ring-porous. In diffuse-porous woods, the vessels are nearly equal in size and are distributed fairly uniformly throughout the growth ring. Softwoods are non-porous woods, since they lack vessels.)

The side walls of vessels contain numerous small bordered pits which connect with those of other conducting elements and with adjacent parenchyma cells.

Vessels range from 0.3 to 1.0 millimeters in length, averaging approximately 0.5 to 0.6 millimeters. They are not more than 5 to 10 percent longer than the cambial mother cell from which they originated, and, in certain instances where there is great lateral expansion of the vessel element during maturation, they may be slightly shorter than the mother cell. The cross sectional areas of vessels, and volumes as well, become greater in the outer layers of the stem.

The volume of vessels depends upon the size and number, and varies greatly in different hardwoods and in individual growth rings and portions of

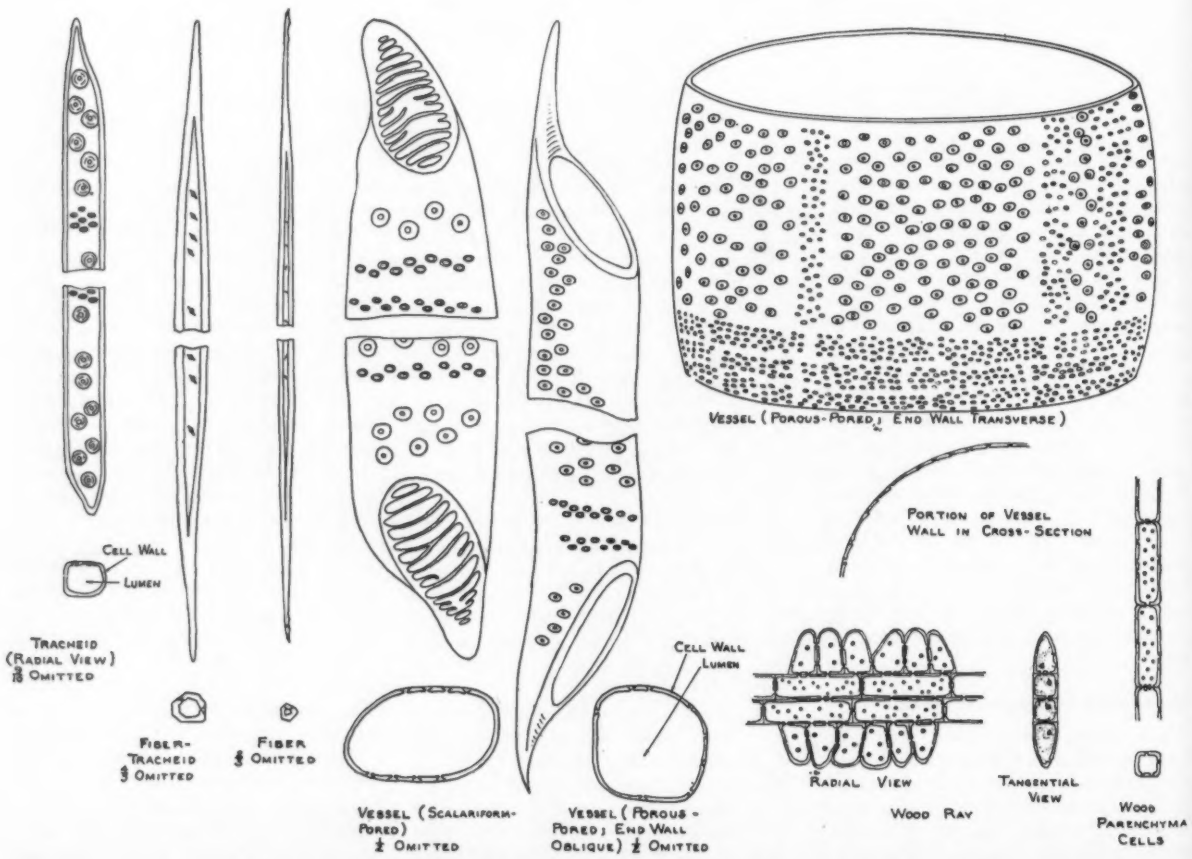

Figure 6—Drawing of several types of cells from Macerated Wood. The three cell types shown at the left are the principal ones of value in papermaking.

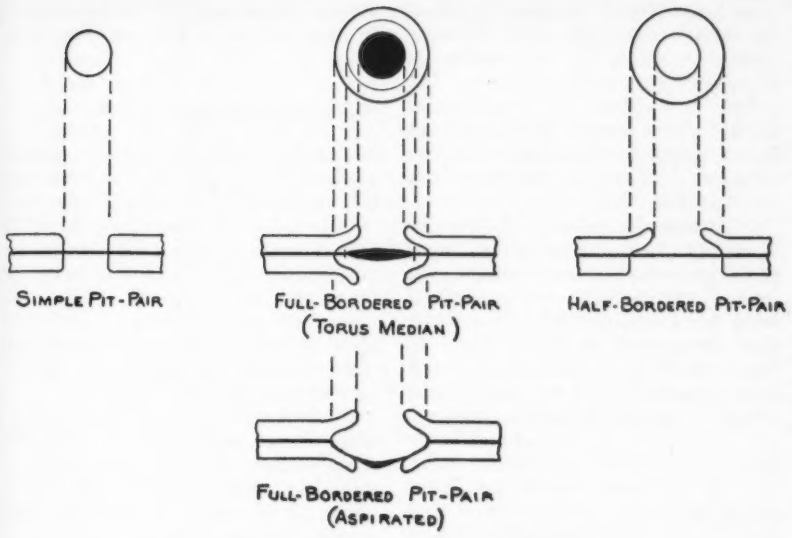

Figure 7—Diagram showing pits in face view and section.

rings. Growing conditions and other factors influence the size and number of vessels produced during any given season and in any specific portion of the tree. Since the vessel content of woods varies within wide limits, even in the same tree, it is evident that any figure on volumetric composition regarding this element can be only approximate. The vessels in certain woods occupy less than 50 percent by volume while in others they compose well over half of the wood.

3. Fibers (Figures 5 and 6). The principal function of fibers is support. They compose the bulk of the cells (by number) of many hardwoods and are found occasionally in softwoods. Fibers vary greatly in form and type but, in general, possess the following characteristics: (a) vertically elongate, slender cells with sharp-pointed, often forked ends, (b) very small cross sectional area, with the lumen often occupying less than half the diameter of the cell, (c) mostly angular in outline, and (d) typically thick-walled but often thin, occasionally with a gelatinous inner layer.

The side walls often contain very small bordered pits, although the borders are so inconspicuous as to give the appearance of simple pits. Often the openings into the pits (pit mouths) are oriented at such an angle to each other that they form a cross. The reduced pits, small central cavities, and thick walls make fibers unsuitable for water conduction but enhance their value as supporting elements.

Mature fibers may be nearly ten times longer than the cambial mother cell from which they came. The short fibers elongate most. During this elongation "sliding growth' occurs in which the ends of the cells are forced between those above and below, which tend to make the wood compact and strong.

Fibers vary from approximately 0.5 to 3 millimeters in length. Their slender form and moderate length make them suitable elements for papermaking. Fibers and fiber tracheids (to be discussed later) form the principal fibrous material in hardwood pulp. Often more than 50 percent of the volume of certain hardwoods is composed of these elements, but the amount may fall below 25 percent in other woods.

4. Fiber Tracheids (Figures 5 and 6). No clear cut line of separation can be drawn between certain types of fibers and wood tracheids. One cell type grades imperceptibly into the other. These intermediate elements are known as fiber tracheids. They occur in both softwoods and hardwoods, often in greater abundance in the vicinity of vessels in the latter. Typical fiber tracheids have taper-pointed ends, medium to thick walls, and small bordered pits. They are vertically elongate cells with a medium to small central cavity.

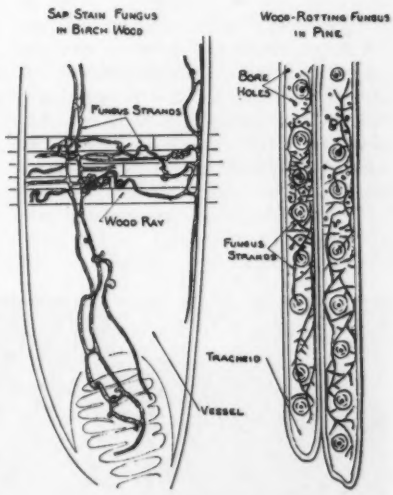

Figure 9—At left, drawing of a portion of a vessel and an adjacent wood ray, showing the invasion of wood-staining fungus strands in birch. At right, drawing of a portion of two adjacent tracheids of pine, showing a wood-destroying fungus.

Elongation of fiber tracheids during maturation is considerable. The mature element may attain a length four or five times that of the cambial mother cell from which it came. Along with fibers and tracheids they compose the principal fibrous mass of hardwood pulp used in paper manufacture.

5. Wood Rays (Figures 2 to 6). Wood rays are composed of living (or living and dead cells) and serve the function of food storage and lateral conduction. Since they vary in size,

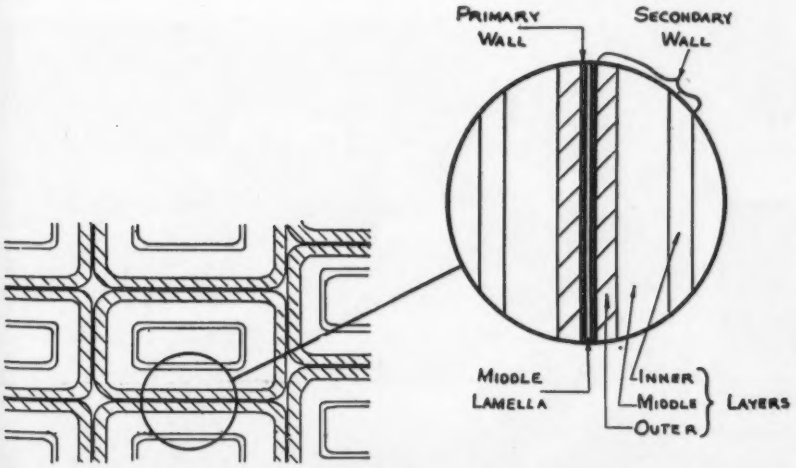

Figure 8—Diagram of cells in cross section, and an enlargement of a portion of two adjacent walls, showing the wall layers.

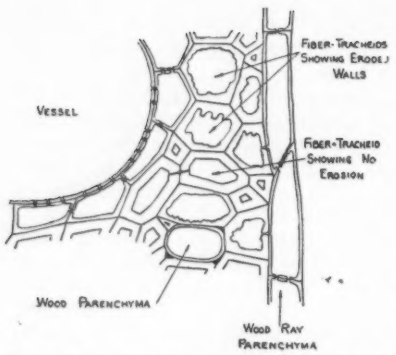

Figure 10—Drawing of a portion of birch wood in cross section, showing erosion of the cell walls due to a wood-destroying fungus.

shape, number, and structure, they are valuable diagnostic features of wood. All the cells composing the ray may be similar and horizontally elongate (Like bricks in a wall), or one or more marginal layers may be different in shape from the others, and arranged vertically. In hardwoods all of the ray cells of the sapwood are living, but in some softwoods the marginal rows of cells are dead. Ray parenchyma cells are typically brick shaped with rather thin walls containing simple pits. They contain protoplasm (cell contents) which is a common feature of all parenchyma cells, in contrast to the water-conducting and supporting cells, described earlier, in which the cell cavities are devoid of living content.

The ray volume of woods differ widely. For example, that of red oak is approximately 20 percent, while that of poplar is 10 percent, and white pine, 5 to 6 percent.

6. Wood Parenchyma (Figures 3, 5, and 6). Like the wood rays, wood parenchyma are living storage and food-conducting cells, but instead of being horizontally disposed, are vertically arranged in strands. The individual cells vary from squarish to vertically elongate, with the length often greatly exceeding the width. In diameter they are usually approximately the same as that of the fibers among which they are commonly distributed. Wood parenchyma cells are a constant feature of most hardwoods and occur also in many softwoods. In the latter they contain resin and are called resin cells. Resin cells should not be confused with resin canals which are cavities lined with resin-secreting cells. In contrast to fibers and fiber tracheids, the wood parenchyma cells do not elongate during maturation, but remain nearly the same length as that of the cambial cell from which they were derived.

The volume of wood parenchyma in commercial woods varies from zero to several percent, but is usually low in comparison to that of other elements.

The Cell Wall (Figure 8)

1. Origin. The cell wall is formed at the time of, and shortly following, cell division. It is formed from the living portion of the cell (cytoplasm) by a complicated process involving deposition in the form of tiny plates or by a "chinking in" process. The middle lamella (a thin layer of intercellular material) is first formed and upon this layer are added the primary and secondary cell walls.

2. Structure. (a). Physical nature. The cell wall is made up of aggregates of molecules (micellae, possibly crystalline in nature) which form fibrils. These fibrils may be arranged concentrically or radially and are oriented at right angles to each other in adjacent layers, giving the cell wall a laminated appearance. The layering of the wall may give mechanical support. Pores or channels in this primary system of cellulose are filled with a secondary system of lignin.

The cell wall may be seen to consist of several layers *(Figure 8)* when thin sections are viewed under polarized light. The middle lamella and primary wall are always present but a

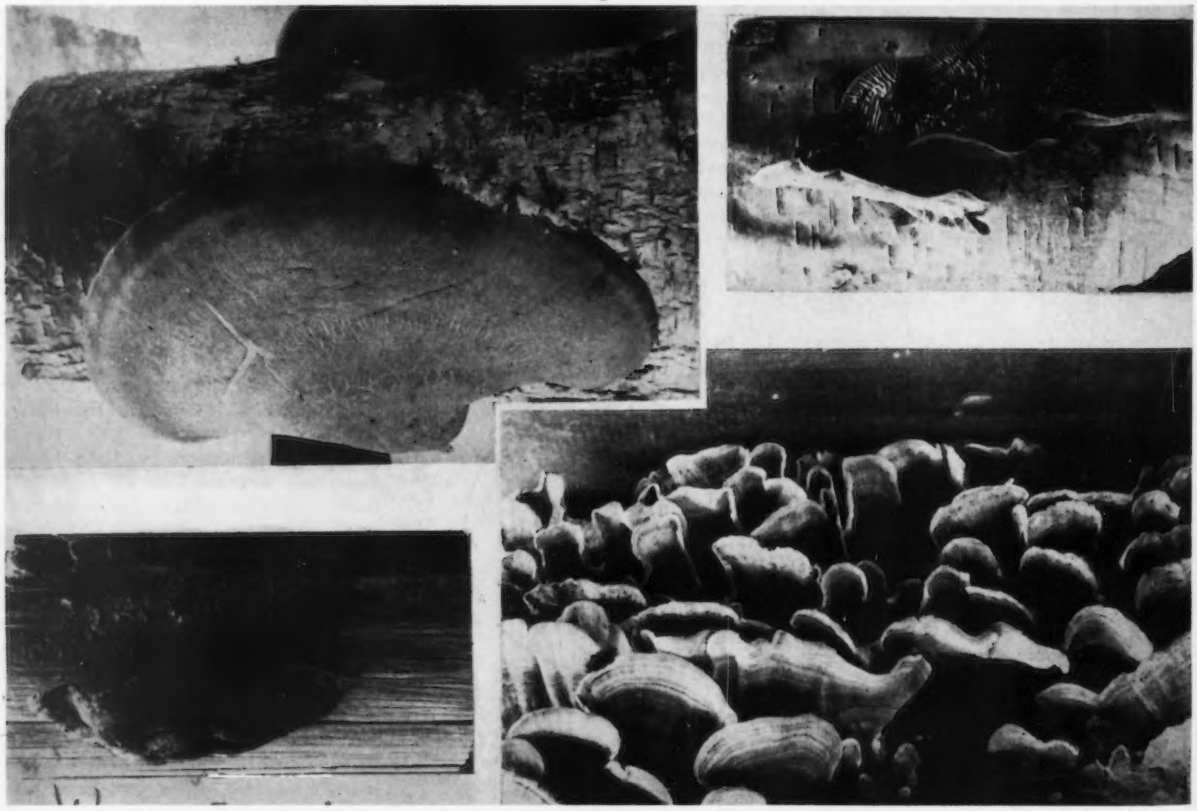

Figure 11—Photographic reproductions, showing "Fruiting" bodies of wood-rotting fungi.

secondary wall may be lacking in some types of wood cells.

Cell walls are not uniformly thickened but contain thin, more or less circular areas, in which there is no continuous secondary wall and the primary wall is thin and membranous. These specialized areas or pits are openings which allow for transfer of water and certain food materials between adjacent cells. During the building of the cell wall these areas remained thin while other portions of the wall were undergoing thickening.

Figure 7 shows several types of pits in face view and cross section. They differ essentially in the method of formation and in the types of cells in which they occur. Three types of pits (or pit-pairs) may be distinguished. Simple pits are those in which the cell wall does not overhang the pit cavity or opening. This type of pit is found in living cells such as wood parenchyma and ray cells. There is no thickening (torus) on the pit (closing) membrance.

Full-bordered pits are those in which the cell wall develops to such an extent around the opening that they overhang the cavity. A thickened impervious pad (torus) is formed on the central portion of the closing membrane. Tori are well developed in the large pits of softwoods but are much reduced or lacking in certain other water-conducting cells and in fibers. Bordered pits are found in dead cells of the water-conducting and supporting types such as tracheids, fiber tracheids, vessels, and wood fibers. In some fibers the borders are reduced to such an extent that they appear simple. The delicate membranes of bordered pits, at least in some conifers, are perforated, and these perforations are large enough to allow the passage of finely divided carbon particles.

Half-bordered pit-pairs are found between living and dead cells, for example between wood rays and tracheids. The wall of the dead cell overhangs the pit cavity while the wall of the adjacent parenchyma cell lacks a border. The closing membrane shows little or no thickening in the form of a torus.

b. Chemical Nature (Figure 8)

Middle Lamella. This is composed of intercellular protoplasmic material laid down early in the formation of the cell. Later some cellulosic and considerable pectic substances are added and, later yet, the layer becomes heavily lignified, especially in thick-walled cells. This is the layer which is weakened or dissolved away by chemicals during the pulping process, allowing the cells to separate freely.

Primary Wall. The primary wall is at first mesh-like with the pores or minute spaces probably containing cytoplasm. Later it consists of cellulose and some pectic substances, finally becoming heavily lignified. Layering of the wall is obscure. Often much mineral matter is contained in the primary wall.

Secondary Wall. In early stages the secondary wall is composed of cellulose, or cellulose and hemicellulose. Later it becomes infiltrated by lignin, tannins, oils, and other organic substances. The secondary walls of fibers are often gelatinous. Mature secondary walls are typically three-layered.

Specific Gravity of Woods

The specific gravity of cell wall substance of wood is approximately 1.53. (The specific gravity of wood is determined by dividing the weight of a block of ovendry wood by the weight of a like volume of water.) Woods differ in weight, depending upon the thickness of the cell walls and the amount of space occupied by the cell cavities. The extreme range in specific gravity in woods is approximately 0.04 to 1.40 but most commercial woods range between 0.35 and 0.65. Thus in softwoods such as white pine the specific gravity is near the lower limit of the range for commercial woods, while red oak is at the upper limit.

Latewood is more dense than earlywood, and the wood formed distant from the pith, especially during periods of vigorous growth, is usually more dense than that formed early in the life of the tree. However, during periods of unfavorable growing conditions, especially in hardwoods, the reverse may be true.

Decay and Stain in Wood

Wood is subject to the ravages of certain fungus growths, some of which cause undesirable stains, while others partially or completely destroy the wood cells. Not only lumber and pulpwood may be attacked, but living trees as well.

A fungus is a plant which, in the vegetative stage, is composed of minute branching strands or filaments. When viewed under high magnification it resembles a tangled and knotted mass of thread. Since fungi do not contain chlorophyll and therefore cannot manufacture their own food they must derive their energy either from the stored food found in the wood or from the cellulose or lignin or the cell wall itself.

Wood-staining fungi do not destroy the cell walls (except those of parenchyma) but merely utilize the food stored in the cells. *Figure 9* shows a concentration of rather large fungus strands in a wood ray of birch. The piece of wood from which this section was taken was sound but contained a bluish discolored area near the surface. The fungus strands are not confined to the ray cells but occasionally ramify through the vessels, where they apparently do little or no damage. Wood containing blue stain is undesirable for pulp because the product obtained from it is discolored. However, bleaching reagents may be added to whiten the product.

Wood-destroying fungi have a more devastating effect upon the wood, since they destroy the portions which are utilized for paper-making. This group of fungi destroy the cells by enzymic action, resulting in erosion of the walls *(Figure 10)*. The rather fine fungous strands pass readily from cell to cell by dissolving holes (bore holes) in the cell walls or by passing directly through the pits *(Figure 9)*. Large pads or masses of fungous threads may be seen in wood which is in an advanced stage of decay.

The presence of fungi in wood may not be evident until the "fruiting" bodies are formed. These structures form on the surface of the wood and are composed entirely of fungous tissue. Each kind of fungus has its own characteristic type of fruiting body, which affords a valuable means of identification *(Figure 11)*. The presence of a fruiting body on a piece of wood indicates that the fungus has already done its work and that the wood, at least in that vicinity, is either partially or completely destroyed. In order for a wood-rotting fungus to thrive it must have a favorable temperature and an adequate supply of moisture, air (oxygen), and food. Unpeeled or unsplit logs lying on damp ground in the woods usually succumb readily to the attacks of fungi. The common practice of peeling pulp bolts and piling them in a dry place where there is a free circulation of air greatly reduces the loss due to decay.

Summary

In this article, a brief discourse on the fundamentals of wood structure is presented, with emphasis being placed on those phases of the subject which have a direct bearing on the pulp and paper industry. The minute structure of wood is considered in somewhat detail because of its greater relative importance. The growing points of the stem are reviewed in order to obtain a better understanding of how a tree grows. Cells, tissues, and organs of the plant are briefly discussed from the standpoint of both structure and function. A cursory treatment of the physical and chemical nature of the cell wall is included. The brief section

on stain and decay in wood calls attention to the cause of these defects. All drawings, diagrams, and photographs were prepared especially for this article in order to clarify the text on certain points which might be difficult to comprehend for those unfamiliar with the subject.

Acknowledgments

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Chemistry of Cellulose and Wood

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Introduction

In chemical terms wood is a complex mixture. All the processes for changing wood into pulp suitable for making paper, with the exception of groundwood manufacture, have as their goal a partial separation of this mixture. The separation is not complete, however, and the resulting pulp is itself a complex mixture containing not only some of the original components of the wood but also degradation products formed during the process of pulping. An understanding of what takes place during pulping and an appreciation of the chemical properties of the resulting pulp depend on knowledge concerning the chemical nature of the materials involved.

The Components of Wood

The chemical components of wood can be classified as follows:

I. Main Components of the Cell Wall
  A. Total Carbohydrate Fraction (70 to 80 percent of the wood)
    1. Cellulose
    2. Hemicellulose
  B. Lignin (20 to 30 percent of the wood)

II. Extraneous Materials
  A. Volatile Oils and Resin Acids
  B. Fixed Oils (fatty oils)
  C. Natural Dyestuffs
  D. Tannins
  E. Ash
  F. Organic Nitrogen Compounds
  G. Other minor constituents

In the present discussion we will consider only the major cell wall components, cellulose, hemicellulose, and lignin, with particular emphasis on the first two.

Cellulose

The term cellulose is frequently used loosely to describe carbohydrate material which contains a relatively high proportion of the polymer of glucose to which chemists refer when they speak of true cellulose. Cotton consists almost entirely of true cellulose, but in wood the true cellulose is associated with small quantities of other high polymeric material, such as polymers of mannose, which have similar physical and chemical properties. Chemically pure cellulose is very difficult if not impossible to isolate from wood, but this fact is of minor importance to the pulp and paper chemist for whose purposes a mixture consisting chiefly of cellulose is usually satisfactory.

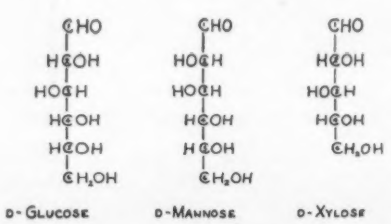

Figure 1—Some Monosaccharides from Wood

The substance cellulose is the largest single component present in wood. For more than a century, it has been the object of study by organic chemists but the final proof of its structure could not come until the fundamental chemistry of glucose had been firmly established and precise experimental techniques had been developed. Since an understanding of cellulose is dependent on an understanding of the structure of glucose, a review of some features of the chemistry of that monosaccharide will be taken up at this point.

The Structure of Glucose

The formula for gluecose usually given in elementary organic chemistry texts shows a six carbon compound having an aldehyde group on one end and hydroxyl groups on the other five carbons *(Figure 1)*. Because of spatial considerations (groups attached to a carbon atom are arranged in space as though they were at the vertices of a regular tetrahedron) whenever four different groups are attached to one carbon atom, the groups can assume two different arrangements which are mirror images of each other. These forms, because of their effect in rotating a beam of polarized light, are called dextro and levo forms. It can be seen from the formula shown in *Figure 1* that carbons two, three, four, and five in glucose are asymmetric; i.e., each is attached to four different groups. The actual configuration of each carbon is indicated by the position of the OH group in the formula; if it is on the right, dextro configuration is indicated, while in the levo form it is on the left.

Mannose, another monosaccharide

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isolated in small quantities from wood, differs from glucose only in the configuration of the number two carbon, as can be seen in *Figure 1.* Xylose, however, which can also be isolated from the hydrolysis products of wood, is a pentose, or five carbon sugar, but resembles glucose in the configuration of carbons two, three, and four as shown in *Figure 1.*

Because of the valence angles between carbon bonds (approximately 108°) in a six carbon chain like that possessed by glucose, carbons one and five approach each other closely. This brings the hydroxyl group on carbon five in close proximity to the aldehyde group of carbon one with the result that the two may interact to form a cyclic hemiacetal group, as shown in *Figure 2.* In forming the cyclic hemiacetal, carbon one becomes asymmetric and, as shown in *Figure 2,* can have either the dextro or levo structure. In $\alpha - D -$ glucose this carbon has the dextro form and in $\beta - D -$ glucose it has the levo. When the ring thus formed contains five carbons and one oxygen, it is referred to as a pyranose ring. In some cases hemiacetal formation is between the aldehyde group and the hydroxyl group on the fourth carbon. In such an instance a furanose ring is formed.

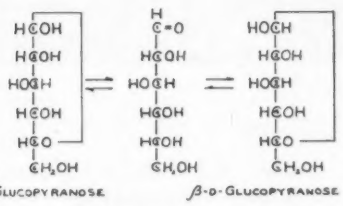

Figure 2—Cyclic Hemiacetal Formation

The structure of glucose in the cyclic form which results from the hemiacetal formation can better be shown by the hexagonal perspective formulas shown in *Figure 3.* In these formulas the ring structure is drawn as though one were viewing a model of the molecule from a position slightly above one edge. An OH group, written below a carbon atom, indicates that it extends below the plane of the ring and represents the dextro configuration; while the levo configuration is represented by OH's written above a carbon atom indicating that they extend above the plane of the ring. The student should practice writing these formulas until the significance of each part becomes clear.

Glucosidic and Glucosidic Bonds

When glucose reacts with methyl alcohol in the presence of concentrated hydrochloric acid, the OH of the hemiacetal group reacts with the OH of the methyl alcohol to form an ether-like linkage known as a glucosidic bond. The resulting compound is called a glucoside. Considering the configuration of the hemiacetal hydroxyls in $\alpha -$ and $\beta - D -$ glucose *(Figures 2 and 3)* one would expect two methyl glucosides to be possible, and such is the case. Their structures are shown in *Figure 4.*

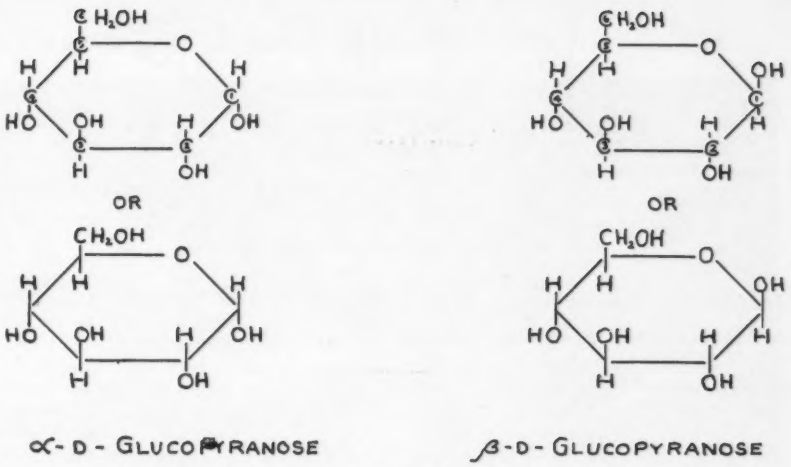

Figure 3—Conventional Hexagonal Formulas for α—D and β—D Glucopyranose

Glucosides, or rather glycosides to use a more general term, are exceedingly common in nature. When any organic hydroxyl compound, usually an alcohol or phenol, is combined with any sugar unit in the manner described above the combination is called a glycoside of which glucosides are a specific type. All glycosides are capable of existing in either $\alpha -$ or $\beta -$ forms.

The hydroxyl groups on the second, third, fourth, or sixth carbons of a cyclic monosaccharide in the pyranose form are themselves available for combining with the hemiacetal group of another monosaccharide unit to form a glycosidic bond. This is the manner in which glucose units are attached together to form the polysaccharides starch and cellulose. In starch, the glucosidic bonds have the $\alpha -$ configuration, but in cellulose they are $\beta -$.

The binding together of glucose units by $\alpha -$ and $\beta -$ glucosidic bonds is illustrated in *Figure 5.* A molecule of the disaccharide maltose, a product of the hydrolysis of starch in which the glucosidic bond has an $\alpha -$ configuration is shown. Also shown is the formula of cellobiose, a dissaccharide resulting from the hydrolysis of cellulose, in which the two glucose units are bound together by a $\beta -$ glucosidic linkage. In the cellobiose formula the right hand glucose residue is shown as though rotated on its horizontal axis through 180° so that it is viewed with the side of the ring having the oxygen atom nearest the observer. Such rotation is necessary to bring the hydroxyl on carbon four in proper geometric position for glucoside formation.

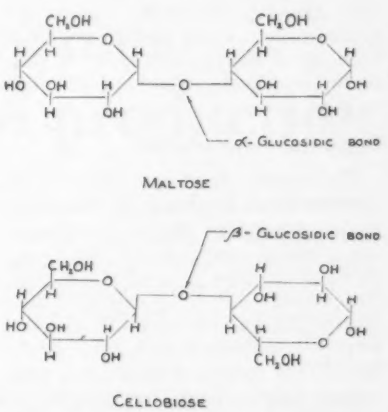

Figure 5—Glucosidic Bonds between Glucose Units in Maltose and Cellobiose

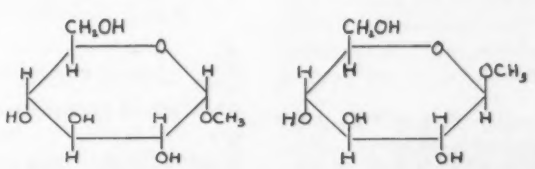

Figure 4—Glucoside Formation

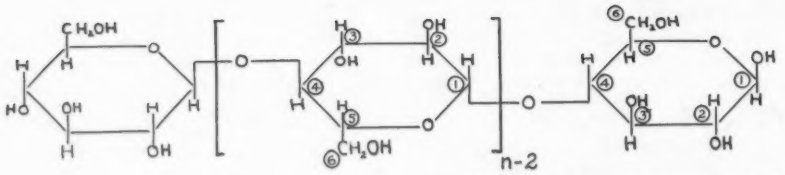

Figure 6—Generally Accepted Formula of Cellulose

The Structure of Cellulose

Cellulose, itself, is generally believed to consist of a long chain of anhydroglucose residues bound together through their first and fourth carbon atoms by β – glucosidic linkages. The formula is shown in *Figure 6*. Here again the alternate anhydroglucose residues are inverted to bring about the proper geometric relationships for the β – glucoside bonds.

The α – and β –linkages in the structures of starch and cellulose, respectively, are of great practical importance. The α – glucosidic bonds in starch are readily hydrolyzed to glucose by enzymes in the saliva and digestive juices of mammals. These same enzymes, however, are unable to hydrolyze the β – glucosidic bonds found in cellulose and the glucose units bound together by these β – linkages are unavailable to mammals as food. Enzymes produced by certain microorganisms, especially soil bacteria, on the other hand, exert a powerful hydrolytic action on β – glucosidic linkages and hence rapidly degrade cotton cloth, wood, or other cellulose containing material, as men in the pulp and paper industry know to their sorrow.

Degree of Polymerization

The number of glucose units in the cellulose chain is known as the degree of polymerization and varies over a considerable range among the molecules of a given sample of cellulose. The average degree of polymerization for the molecules in a sample of cellulose is commonly referred to as the D. P. The values of D. P. may vary widely between different samples of cellulose, depending on source and previous treatment. In the natural state it may be over 5000, as in the unopened cotton boll, but may be only 250-300 in some rayon samples. If the D. P. falls below 125 the cellulose loses its fibrous character and becomes friable.

The distribution of molecules having different chain lengths is known as the D. P. distribution, and may be of considerable interest to users of cellulose. Manufacturers of strong rayon for example, desire long cellulose chains in their cellulosic raw material. In the manufacture of certain special types of paper, such as that required for currency, a high degree of polymerization is essential, but for other papers in which softness and open texture are desired, a low D. P. is beneficial.

The D. P. is commonly determined by dissolving the cellulose in Cuprammonium or cupriethylenediamine solutions under definitely specified conditions. The viscosity of the resulting solution is a function of the average D. P. of the sample. A high viscosity indicates high D. P. The viscosity value may be used to determine an actual value for the D. P. by means of an appropriate equation, but for most control purposes, the viscosity is correlated directly with the properties desired in the pulp.

Hydrolytic Degradation of Cellulose

The glucosidic bond is sensitive to hydrolytic rupture in the presence of acid. In the reaction, a molecule of water reacts with a glucosidic bond splitting apart the adjacent glucose units, one with an OH restored on its fourth carbon and the other with the OH restored to the potential aldehyde (hemiacetal) group. The resulting fragments of the original cellulose chain may still have relatively high D. P. figures, but as this process continues the average D. P. of the cellulose sample decreases until finally the process, if continued long enough, will produce pure glucose. This type of hydrolytic degradation takes place whenever cellulose comes in contact with an acidic solution, and explains why sulfite pulping, which is carried out under acid conditions, produces pulp with lower average D. P. than the alkaline processes.

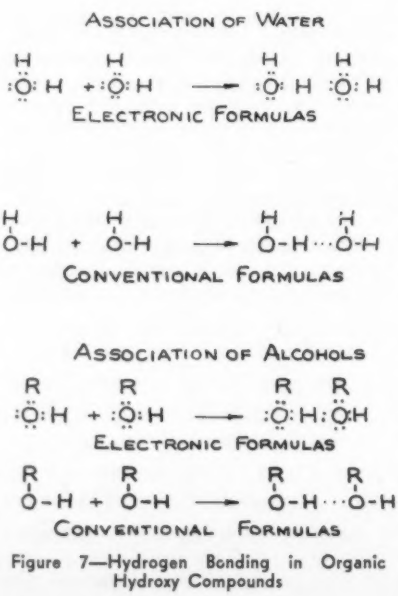

Figure 7—Hydrogen Bonding in Organic Hydroxy Compounds

Other Reactions of Cellulose

A consideration of the cellulose formula in *Figure 6* reveals that there are three parts to the molecule. There is first a "reducing end group," consisting of the glucose unit shown on the right of the formula in which the potential aldehyde (hemiacetal) group is not combined by glucosidic bonds with other glucose units. The potential aldehyde group is easily oridized and shows the reducing properties characteristic of the similar groups in the monosaccharides. It is capable of reducing Fehlings solution and ammoniacal solutions of silver, but because there is only one reducing end group in the long cellulose chain the amount of reduction brought about by a sample of cellulose may be very slight. The shorter the cellulose chains become, however, the greater the number of reducing end groups there are to react so that the "copper number" reflects the D. P. of the sample; a high copper number indicates a low D. P.

Figure 6 also shows a "non-reducing end group" or glucose unit with four free hydroxyl groups and having its aldehyde group "bound" in a glucosidic linkage. The fact that this glucose unit has four hydroxyl groups has proved of great value in certain procedures for determining the length of the cellulose chain, but a discussion of this method cannot be considered here. The four hydroxyl groups are not greatly different in their reactions however, from the three hydroxyl groups in all other glucose units of the chain and for purposes of our discussion the effect of this non-reducing end group can be disregarded.

The third part of the cellulose molecule consists of (n-2) glucose units each of which contains three hydroxyl groups attached to carbons two, three, and six. The hydroxyls on carbons two and three are secondary alcoholic groups, while that on carbon six is primary. These alcoholic groups enter into the normal reactions of other primary and secondary alcoholic groups forming ethers, esters, and oxidation products.

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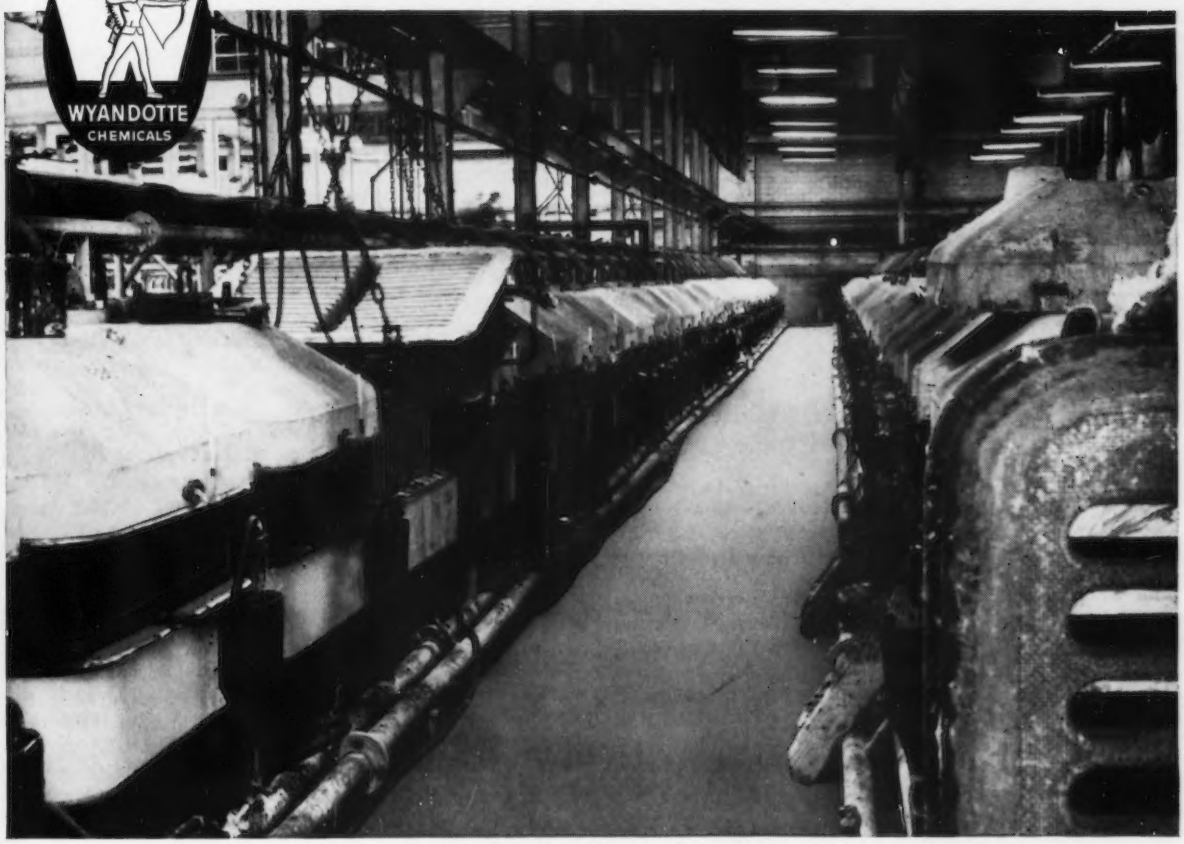

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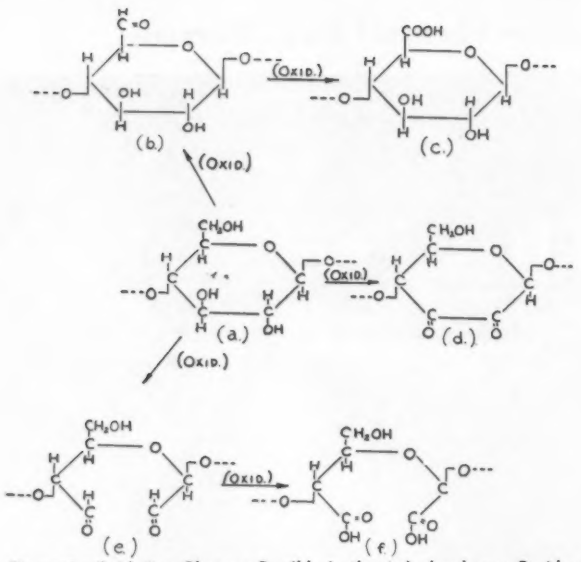

Figure 8—Oxidation Changes Possible in the Anhydroglucose Residue of Cellulose

Like other hydroxyl groups in organic compounds, the alcoholic groups of cellulose are also capable of forming hydrogen bonds with other oxygen containing molecules.[7] It is believed that this hydrogen bond formation is important in retention of water by cellulose, in the binding of the parallel cellulose molecules in the fibers to each other and even in fiber to fiber bonds.

In terms of the electronic theories of structure and valence, water and simple alcohols are believed to have the structures shown in *Figure 7*. In each hydroxyl group of water and the alcohols, the hydrogen atom is bound to the oxygen atom by a pair of shared electrons in a primary co-valent bond. The oxygen atom also has two other pairs of electrons which are unshared and which in some manner exert an attraction for hydroxyl hydrogens on adjacent molecules. There is good experimental evidence for believing that the hydrogen atoms thus bound cause an association of adjacent molecules through this tendency to be attracted by two pairs of electrons on different oxygen atoms.

The hydrogen bonds thus formed are much weaker than the primary valence bonds which bind the atoms of organic molecules together, yet they are of considerably greater magnitude than the vague forces of attraction known as Vander Waals forces.

Crystallinity in Cellulose

The fact that the glucose units in cellulose are bound together by their respective 1:4 positions (by bonds involving groups on the carbons one and four) gives the long chain molecules a symmetrical structure. Molecular scale models substantiate this symmetrical structure and indicate that parallel molecules can pack together closely so that the individual glucose and cellobiose units can assume definite geometrical positions with respect to each other. X-ray photographs of cellulose give a diffraction pattern that definitely establishes the crystal structure of at least a major portion of the cellulose. In the close packing of the crystal lattice there is maximum opportunity for hydrogen bonding to cause the adjacent chains to cling to each other and thus be an important factor in developing strength in the individual fibres.

Oxycellulose Formation

It has already been pointed out that cellulose is degraded by the action of acid. Cellulose is also degraded in a different manner by the action of various oxidizing agents. *Figure 8* shows some of the changes which can occur. As mentioned before, the two secondary and the single primary alcohol groups on each anhydroglucose residue of cellulose *(Figure 8a)* possess properties similar to those of such groups in other simpler organic combinations. The primary alcohol group can be oxidized to an aldehyde *(Figure 8b)* or to a carboxyl group *(Figure 8c)*. The secondary alcohol groups, since they are adjacent to each other, constitute a structure similar to the glycols. These secondary alcohol groups can be oxidized to ketone groups *(Figure 8d)* or the bond between the two carbons can be broken with the formation of two aldehyde groups *(Figure 8e)* which in turn can be oxidized further to carboxyl groups *(Figure 8f)*. Certain special reagents produce specific changes in the cellulose molecule, such as Periodic acid, HIO_4, which will break the bond between carbons two and three, and produce two aldehyde groups as shown in *Figure 8e*. Nitrogen dioxide has a specific oxidative action on the primary alcohol group in position six changing it to a carboxyl group *(Figure 8b)*. In the ordinary treatment of cellulose in the pulp and paper industry these reagents are not commonly employed. On the other

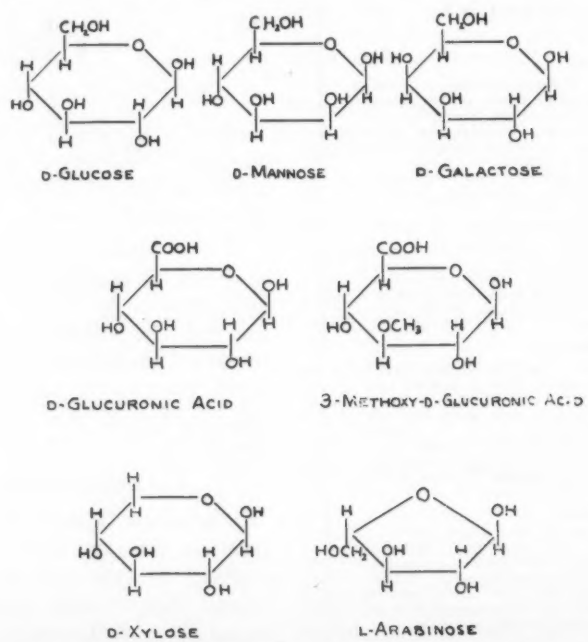

Figure 9—Carbohydrates obtained by the Hydrolysis of Hemicellulose

hand during the bleaching operation and at other stages the cellulose is subjected to the oxidative action of reagents such as chlorine, hypochlorite, chlorine dioxide, hydrogen peroxide or atmospheric oxygen. Of some of these reagents, particularly chlorine dioxide, it is claimed that the oxidative effect is confined to the colored impurities in the pulp and the cellulose is not greatly alerted. Other oxidizing agents, on the other hand, may not only oxidize the coloring matter but may also bring about an oxidation of the glucose units of the cellulose chains. Ordinarily, the oxidation of the glucose unit does not break the chain and lower the degree of polymerization, but if the oxidized cellulose is treated with alkali the chain tends to rupture at those glucose units which have been extensively altered. Atmospheric oxygen in particular may have a powerful degrading effect on cellulose in the presence of alkali. This is one reason why all air must be vented from the digester in the early stages of soda or kraft cooking.

Hemicellulose

We have spoken thus far about the chemical substance cellulose, which is readily recognized as being of prime importance in any consideration of wood, or pulp derived from wood. Let us now examine the somewhat less definite fraction of the wood referred to as hemicellulose. The total carbohydrate portion of wood isolated by methods originally devised by Ritter and others is known as holocellulose. If holocellulose is treated with 17.5 percent sodium hydroxide under definitely specified conditions, a portion of the holocellulose dissolves leaving undissolved the alpha cellulose fraction which is chiefly the chemical substance cellulose. That portion of the holocellulose which dissolves in 17.5 percent sodium hydroxide, is called hemicellulose. This definition is purely arbitrary and makes no distinction between the different types of molecules that may be soluble in such a medium. Thus a comparatively short chain true cellulose molecule might dissolve while another molecule of much higher molecular weight, if it contained carboxyl groups, might also dissolve. In our further discussions we should also distinguish between "natural hemicellulose" and "manufactured hemicellulose." The former consists of undegraded molecules from the original wood which would be soluble in 17.5 percent sodium hydroxide. The "manufactured hemicellulose" on the other hand, has been produced by the degradation of cellulose chains from the original alpha cellulose portion. The properties of these two types of material are entirely different and the hemicellulose analysis of a pulp sample is apt to be misinterpreted unless this fact is borne in mind. The properties of the "manufactured hemicellulose" should be relatively similar to those of the parent cellulose. The natural hemicellulose, on the other hand, is much different and has a pronounced but obscure influence on the properties of pulp and consists of molecular species the structures of which are still largely unknown.

Unlike cellulose, which yields on hydrolysis only glucose, hemicellulose hydrolyzes to a variety of monosaccharide units. Among these are the three hexoses, glucose, mannose and galactose; the pentoses xylose and arabinose; and glucuronic acid and its methylated derivatives. A glance at *Figure 9* which shows the structural formulas of these substances may be instructive.

It will be seen that mannose and glucose differ from each other only in the configuration of the groups around carbon two. Galactose differs from glucose only in the configuration of the fourth carbon. Glucuronic acid and methoxy glucuronic acid represent glucose residues in which the sixth carbon is part of a carboxyl group rather than a primary alcohol group. The xylose residue, as previously mentioned, is exactly like the glucose residue in configuration of carbons two, three, and four, but is a pentose, or five-carbon sugar. Arabinose, another pentose, is like galactose in the configuration of carbons two, three, and four but is shown here in the "furanose" or five membered ring structure, not because this has been established for arabinose in hemicellulose but because arabinose seems to be the carbohydrate most easily removed from wood on hydrolysis. Recent studies on other natural products containing arabinose attribute this type of behavior to the furanose structure. Because both xylose and arabinose are five carbon sugars their polymers would be called pentosans and the ordinary pentosan determination in which the pentose is dehydrated by acid to form furfural would not distinguish between them if both were present.

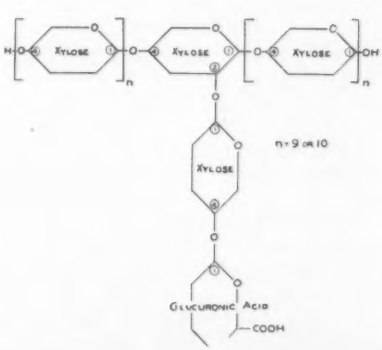

Figure 10—Hemicellulose from New Zealand Flax Isolated by McIlroy

That a portion of the hemicellulose makes a valuable contribution to the properties of pulp has been fully established by numerous studies. The hemicellulose is clearly responsible for rapid beating, the development of maximum bursting strength, minimum opacity, and greaseproof qualities. It is not known, however, whether all portions of the hemicellulose are equally valuable in this regard or whether some fractions contribute more toward one property and less toward others.

So little is known about the chemical structure of the substances found in hemicellulose that we are not yet in position to correlate properties with structure with any degree of certainty. On the other hand, knowing the units of which hemicellulose is composed, we can infer the properties of macro molecules in which these units might be combined in certain ways.

Mannose and xylose have structures so much like glucose that long chains of the units combined through their 1:4 positions would probably have properties similar to the properties of true cellulose. Such straight chains, particularly if composed of mannose units, might even fit into the crystalline pattern of cellulose. This may be the reason why it is so difficult to remove all mannan from the alpha cellulose of certain soft woods. Straight chains composed of mannose or xylose should resemble so closely the properties of cellulose chains that it is difficult to attribute to such molecules the properties which seem peculiar to natural hemicellulose.

Hexuronic acid or methoxy hexuronic acid units might be combined in chains or might be recurring units in chains composed of other units such as glucose, mannose, or xylose. They also might be attached as side groups to such chains. Whatever their manner of attachment, they almost certainly increase the hydrophylic properties of the materials of which they are a part. Alginic acid, for example, obtained from certain sea algae, consists of long chains of mannuronic acid units coupled 1:4. Pectins likewise have a high proportion of hexuronic acids in their molecules. From the water solubility and gelling properties of such materials we can infer the type of property brought to a carbohydrate molecule by carboxyl groups.

As already mentioned, X-ray studies indicate that a large portion of true cellulose is crystalline in nature. Hemi-

cellulose, on the other hand, seems to be largely amorphous. This fact would tend to suggest that there is a lower degree of molecular symmetry found among the hemicellulose molecules than among the molecules of true cellulose. Studies of the synthetic fibers similar to nylon indicate that long chain molecules will only orient themselves in a crystalline pattern if their constituent molecular units are symmetrically bound together and do not have large protruding side groups. These considerations in addition to research reported in the last few years lead us to suspect that we may have carbohydrates in hemicellulose that are linked, not only in the symmetrical 1:4 manner, but 1:2, 1:3, or 1:6. In addition they may have side chains consisting of one, two, or even more carbohydrate units attached at regularly spaced intervals on the main chain.

Structure of Hemicellulose

Only recently have structures been established for any compounds actually isolated from hemicellulose. McIlroy[11] has found that a hemicellulose fraction from New Zealand Flax consists of a chain *(Figure 10)* of 19-21 xylose units coupled 1:4. At the center of this main chain is a side chain consisting of a glucuronic acid unit bound by a 1:4 bond to another xylose unit. The xylose unit of the side chain in turn is coupled 1:2 to a xylose unit of the main chain.

A somewhat analagous structure has been tentatively proposed for a maple hemicellulose fraction extracted with liquid ammonia by Neubauer[12] in the laboratories of the Pulp and Paper Research Institute of Canada. Dr. Neubauer considers the structure of this fraction to be a main chain of xylose units coupled 1:4 with 3-methoxy-glucuronic acid residues substituted in side chains.

It has been known for years that larch wood contains about one and one-half percent of a soluble polymer of galactose. Campbell, Hirst, and Jones[13] have recently found that one fraction of this galactan consists of a chain of galactose units *(Figure 11)* bound together by 1:6 bonds. To every second unit is bound a side chain consisting of one galactose unit attached by a 1:3 glycosidic bond.

The varieties of structures found in these three examples clearly illustrate that there is good reason for believing that the properties of hemicellulose may come from structures considerably different from the long symmetrical chains found in true cellulose. The structures shown have been established only recently and one, in fact, has yet

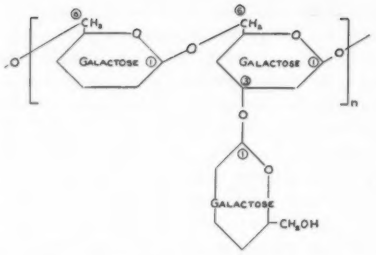

Figure 11—One Fraction of a Galactan of Larchwood Isolated by Campbell, Hirst and Jones

to be reported in full detail. The field, however, is being actively investigated by a number of organic chemists of great skill and the next few years should see our knowledge greatly expanded.

Lignin

The principal non-carbohydrate component of wood which is of concern to the pulp and paper chemist is lignin. From an analytical viewpoint, lignin is the insoluble residue which remains when wood, after suitable extraction to remove tannins, resins, fats, etc., is treated with strong mineral acid.

The chemical composition of lignin is much different from that of the wood components already discussed. Analysis shows a higher percent of carbon than carbohydrate material indicating the presence of aromatic units. Indeed, the fragments isolated from lignin are derivatives of benzene. *Figure 12* shows some of these fragments of known structure obtained from lignin by such processes as destructive distillation, distillation with zinc, fusion with alkali, catalytic reduction, and oxidation. The fundamental unit appears to be n-propyl benzene. Most of the fragments isolated from softwood lignin have a methoxy group meta to the side chain and an hydroxy group in the para position. Thus, through partial removal and oxidation of the side chain, vanillin is the principal material ob-

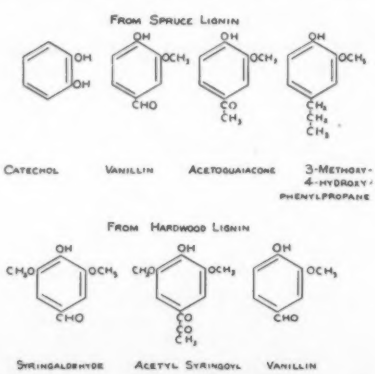

Figure 12—Aromatic Products from Lignin

tained by the alkaline oxidation of lignin. The amount of vanillin potentially available from this source goes far beyond the demands for vanilla flavoring. Extensive research is now in progress to develop new uses for this chemical.

In addition to the guaiacyl structure characteristic of softwood lignin, some of the benzene nuclei in hardwood lignin have the syringyl structure; i.e. have two methoxyl groups ortho to the phenolic group. The ratio of syringyl to guaiacyl groups is approximately two to three. Nothing is known with certainty, however, regarding the manner in which the phenyl propane units are bound together in either hardwood or softwood lignin. Whatever the manner of combination, it is believed by many that several of the individual phenyl propane units are bound together into a larger structure which then becomes the repeating unit in the high polymeric lignin. A greater or less number of these repeating units would make lignin macromolecules of varying size, similar to the condition that exists for cellulose.

One of the problems which plague the lignin chemist is the fact that lignin as it occurs in the plant is a sensitive chemical substance. Almost any chemical process employed to isolate it brings about alteration in the lignin structure so that the final material isolated is not the same as the original material in the living plant. Much work is being done on the chemistry of lignin at the present time and without doubt each year sees the problem nearer solution. At present, we must content ourselves with the knowledge that we have here a polymeric material to which are attached certain functional groups. These groups appear to be: (1) a carbonyl group which is capable of enolizing so as to produce a double bond and an hydroxyl group, (2) phenolic groups, (3) methoxy groups, and (4) alcoholic groups, both primary and secondary. It has been clearly established that there are no acetyl groups and no carboxyl groups.

The properties of lignin as they concern the paper chemist result from the presence of these functional groups. Phenolic groups are weakly acidic and tend to make the lignin soluble in strongly alkaline solutions. The lignin molecule is also capable of reaction with the bisulfite ion in a manner not yet fully understood. Erdtmann[14] is of the opinion that there is a reaction between the bisulfite ion and hydroxyl groups in the lignin. Regardless of the mechanism there are reactive centers in the lignin to which bisulfite ions become attached producing lignin

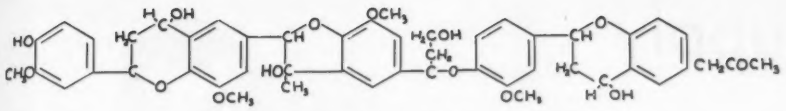

Figure 13—Suggested Structural Formula for Lignin

sulfonic acid which is then water soluble. This forms the basis of the sulfite process for the removal of lignin from wood to make sulfite pulp. The soda process is primarily concerned with solubilizing the lignin through the reaction of alkali with the phenolic groups. In the kraft process, wood is treated with a mixture of sodium hydroxide and sodium sulfide which introduces SH groups. The lignin is thus made more soluble in alkali and can be removed under less drastic conditions in the kraft than in the soda process.

There is evidence that some kind of a chemical union exists between the carbohydrate and lignin in wood. The nature of this combination is uncertain but if it exists one of the first steps in the removal of lignin is the breaking of this lignin-carbohydrate bond.

Although the structure of lignin is not known, many workers have come forward with suggested formulas which to a greater or less extent aid in understanding some of the properties of lignin. One of these formulas put forward for purposes of discussion by Brauns[8] is shown in *Figure 13*. It should be clearly understood, however, that this formula is merely suggestive and is not substantiated by sufficient experimental evidence. It is the feeling of some lignin chemists, in fact, that even tentative detailed formulas for lignin are not yet justified. It will be noted in the formula that the three carbon side chains of the various phenyl propane units are involved in the formation of heterocyclic rings of the pyran (five carbons and one oxygen) or furan (four carbons and one oxygen) type. Structures of this kind are common among such natural products as the coloring matter of leaves and flowers and certain tannins.

When one considers that approximately one-fourth of the weight of all wood used by the pulp and paper industry is lignin and that as yet no large scale use for the material has been found the magnitude of the problem involved in its economical disposal becomes evident.[15] In the more efficient mills which manufacture soda and kraft pulp the waste "black liquor" containing lignin is burned to recover the chemicals and the fuel value of the organic matter. The waste liquor from the sulfite process, however, is still almost universally wasted. The pollution problem thus created is receiving more and more attention and legislation now on the books or certain to be passed in the near future is forcing a change of procedure on the part of industry. Much research is being carried out at the present time toward finding large scale uses for lignin. As knowledge of its fundamental structure increases the uses for lignin will become more apparent.

The manufacture of paper is one of the ancient arts. The application of chemistry in obtaining paper making materials is of only comparatively recent origin and for more than a century has made its rapid development through the use of largely empirical reactions. The time has now come, however, when future progress must depend in large measure on a careful consideration of the chemical nature of the materials involved. The fundamental knowledge concerning cellulose is in a well advanced state but much remains to be learned concerning hemicellulose and lignin in order that these potentially valuable materials can be utilized more intelligently.

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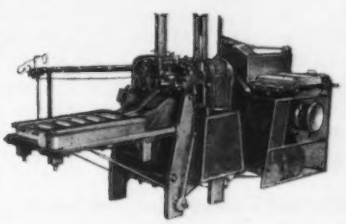

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The Wood Supply

Henry J. Perry[1]

Connected with Bennett Ltd., 1925-28; Arthur D. Little, 1928-30; J. P. Lewis Co., 1930-1945; Frederick C. Clark Associates, 1946-1949; Paper Trade Journal since 1949. Mr. Perry has been active in the technical manufacturing, converting and management phases of the industry and has served as a consultant to many well known concerns.

Wood Supply, Past, Present, and Future

Since the general acceptance of wood pulp as a paper making raw material in the late 1800s, pulp wood harvesting has become a major branch of the forest industry.

Today wood pulp is the third largest consumer of all wood, ranking only below lumber and fuel wood on a volume basis. From a practical standpoint it ranks second to lumber, as fuel wood consumes large quantities of tops, limbs and culls not suitable for lumber or pulpwood.

Originally the forest lands in United States were thought to have contained 8,000 billion board feet of timber. In 1945 this amount had shrunk to about 1,601 billion board feet. The difference plus that grown in the meantime has been used or destroyed. The pioneer instinct and lack of a practical forest program have been the major factors contributing to this startling condition.

Today the lumber and wood pulp industries are actively competing for the log supply. In some regions, available wood has practically disappeared with the resultant shutting down of mills, unemployment and economic loss. However, while the situation is serious, it is not hopeless by any means if constructive measures are taken now, and faithfully carried into the future.

Pulpwood Consumption and Supply

Pulp making has geographically followed the lumber industry. Starting in New England it moved westward along the northern tier of states to Wisconsin and Minnesota, thence to the West Coast. It then moved into the southern tier of states upon the development of southern pine pulps. Still more recently the timber reserves of Alaska have been opened up for utilization.

Thus we have well defined wood pulp producing areas, namely:

The Northeast, comprising New England, New York, Pennsylvania, New Jersey, West Virginia.

The Lake Region, comprising Michigan, Wisconsin, Minnesota.

The Pacific Northwest, comprising Oregon, Washington.

The South Atlantic, comprising Virginia, the Carolinas.

The Southeast, comprising Georgia, Florida, Alabama, Mississippi.

The West Gulf, comprising Louisiana, Arkansas, Texas.

In these regions is located the bulk of our commercial forests and pulp mills.

The preferred species in the Northern regions are the spruces and firs; in the Pacific Northwest, Sitka Spruce, Western Hemlock and Fir; while in the South it is the pines. It will be noted that all of these are coniferous species. The deciduous species are being used in increasing amounts as regional shortages occur and pulping technology advances. Aspen, birch, maple, and the gums are acceptable for pulping.

The consumption of pulpwood is a direct indicator of the growth of the industry. *Table I* shows its growth.

It should be noted that in 1899, New York, Maine, and Wisconsin were the leading pulpwood consuming states. In 1945, New York had dropped down and Washington, Maine, Wisconsin, Florida and Louisiana each were consuming over a million cords per year.

The wood pulp production record is given in *Table II*.

While wood pulp, new supply (production plus imports less exports) has followed the increased demand, the use of United States produced wood pulp has not held its own, except during war years. We are dependent on Canada and Scandinavia to make up the deficit. With the current expansion underway and in the planning stages, North America will be self-sufficient and may even have an exportable surplus.

The dependency is no new occurrence as wood pulp has been imported since 1907 and has reached a peak of 2¼ million tons. Canada currently is supplying the bulk of the imported raw material. This is the equivalent of 5 to 6 million cords of wood, to which must be added 5 to 6 million cords equivalent to the newsprint we are importing plus up to 2 million cords of pulpwood yearly. Thus, we fail to supply about 10-13 million cords from our own domestic forests.

The ratios between new supply and paper and paper board vary only slightly over many years. However, the amounts supplied by foreign sources varied from a peak of 20 per cent in 1929 to the current average of 10 to 12 per cent. The importation of wood pulp to the United States also varies to some extent according to the demand for dollars and government regulation.

Present Forest Resources

The results of the U. S. Forest Service Survey[2] made in 1945, states that the saw timber stands contain approximately 1,600 billion board feet based on nine inches DBH (Diameter Breast High) minimum. The volume

[1] Editor, *Paper Trade Journal*, New York 19, N. Y.

[2] Reappraisal of the Forest Situation in the U.S. USDA Misc. Report 668.

TABLE I

Total U.S. Pulpwood Consumption

	Cords
1899	1,986,000
1909	4,001,000
1919	5,477,000
1929	7,645,000
1939	10,816,000
1949	19,945,000
1951	26,576,000

Source, Census.

TABLE II

U.S. Woodpulp Production

	Short Tons
1899	1,179,000
1909	2,495,000
1919	3,517,000
1929	4,862,000
1939	6,993,000
1949	12,171,000
1951	16,519,000

Source, Census.

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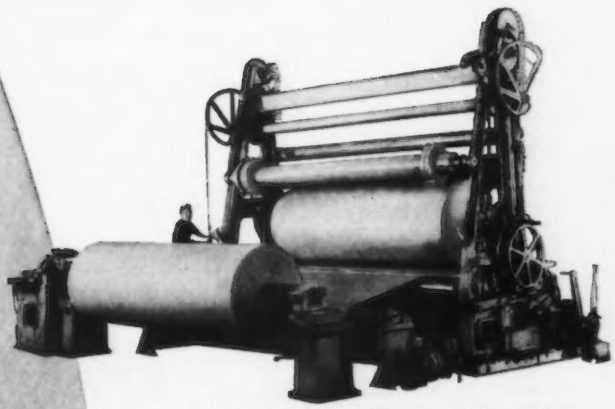

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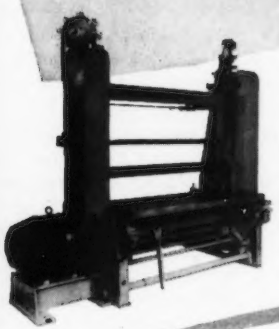

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TABLE III

Balance Sheet 1945, Saw Timber Pulpwood Regions

Millions of Board Feet

North

Region	Softwood Growth	Softwood Drain	Softwood Net Drain or Gain	Hardwood Growth	Hardwood Drain	Hardwood Net Drain or Gain
Northeast	910	1,438	— 528	889	766	+ 123
Middle Atlantic	597	582	+ 15	2,115	1,722	+ 393
Lake	346	839	— 493	1,057	1,167	— 110
	1,853	2,859	— 1,006	4,061	3,655	+ 406

The softwood drain exceeds the annual growth by 50% for softwood species, while hardwoods actually increase in growth.

South

Region	Softwood Growth	Softwood Drain	Softwood Net Drain or Gain	Hardwood Growth	Hardwood Drain	Hardwood Net Drain or Gain
South Atlantic	4,016	4,301	— 285	2,090	1,843	+ 247
Southeastern	5,284	7,538	— 2,254	2,940	4,386	—1,446
West Gulf	3,619	3,798	— 179	1,989	3,033	—1,044
	12,919	15,637	— 2,718	7,019	9,262	—2,243

In these regions the anual net drain of softwood exceeds the annual growth by 21%. Hardwoods have a net loss of 33.8% of annual growth.

Pacific Northwest

Region	Softwood Growth	Softwood Drain	Softwood Net Drain or Gain
Pacific Northwest			
Douglas	3,669	11,981	— 8,312
Pine	483	2,526	— 2,043
	4,152	14,507	—10,355

Source: USDA.

TABLE IV

Drain by Commodities and Regions, 1945

Millions of Board Feet

Region	Total	Lumber	Fuel	Pulpwood	Other Commodities	Destructive Agents (Fire & Disease)
Northeast	2,204	864	156	590	297	297
Middle Atlantic	2,304	1,361	254	157	433	97
Lake	2,006	1,170	98	382	236	120
Central	2,342	1,479	264	32	353	214
North	8,856	4,874	772	1,161	1,319	728
South Atlantic	6,144	3,536	808	586	576	638
Southeastern	11,924	6,867	1,222	737	1,866	1,232
West Gulf	6,831	3,819	693	487	1,428	404
South	24,899	14,222	2,723	1,810	3,870	2,274
Pacific Northwest	14,532	10,877	154	1,758	1,254	489

Source: USDA.

TABLE V

Comparison Total Drain to Pulpwood Drain, 1945 Saw Timber

Millions of Board Feet

Region	Softwood Annual Drain	Pulpwood Drain	Percent of Pulpwood Drain to Total Drain
Northeast	1,438	590	41%
Middle Atlantic	582	157	27%
Lake	839	382	46%
Central	120	32	27%
South Atlantic	4,301	586	14%
Southeastern	7,538	737	9.8%
West Gulf	3,798	487	12.8%
Pacific Northwest	14,507	1,758	12%

Source: USDA.

of all timber five inches DBH is believed to be 470 billion cubic feet. This volume contains all species in all regions.

The distribution shows that the major reserves are located West of the Rocky Mountains and are primarily in virgin stands, where death from age and decay often balance growth.

It is upon this 470 billion cubic feet that we must depend for all raw material for all forest industries as well as our growing stock.

Before getting too involved in this Forest Reappraisal report of the U. S. Forest Service it is wise to state that many professional foresters do not agree as to its findings. In fact some claim that in some locations the figures are 30 per cent too low. Nevertheless, so far as is known it is the only report of its type available. Even if growth and drain are in balance, as some believe, there is plenty of room for improvement, to prepare for future consumption of wood. This is a long range program at best.

It will be noted that of all regions the North is the only one in which total growth exceeds total drain, and it should also be noted that it has the lowest reserve. These facts may lead to a feeling that all is well. However, it must be remembered much of the Northern stands are second or third growth and the drain is being taken from the better stands, leaving the scrub stock. Also, as the coniferous species are removed, less desirable deciduous species move in.

The same is true in the Southern regions, while in the West the overcutting is a benefit for it is removing over-ripe, static growth.

To further illustrate the depletion, consider the all important Saw Timber Balance as summarized in *Table III*.

The net loss in the Pacific Northwest is 2.7 times the growth. This appears to be a serious condition; however, the major cut comes from virgin stands upon which little growth occurs. The removal of this growth will bring the area back into a productive condition again.

The above figures show the amounts of available supply and the effect of all types of drain. They also indicate where the major shortages are most likely to occur.

As high grade timber gets more scarce, competition for available supply becomes keener.

Lumber, under the increasing pressure of new housing projects is increasing in demand. Pulpwood demand is just as rapidly increasing. Of the total drain, it consumed 4 per cent in 1929, 6 per cent in 1936, 11 per cent in 1944, about 15 per cent in 1948 and this demand has continued to increase.

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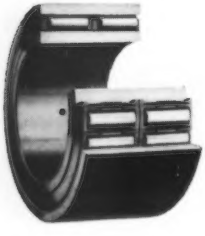

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Table IV shows drain 1945 by use and region.

Table V shows a comparison of the total drain to pulpwood drain. With the increasing demand for pulpwood, the small proportion used for this purpose is quite surprising compared to the total drain, except in the Northern and Lake regions. This probably is due to earlier lumbering in the North, where white pine was the principal species removed, thus causing a decline in the lumber industry in the Northeast.

The present position shows that we are fast cutting into our timber reserve and that the Northwest remains our principal reserve supply.

In some regions the quality as well as quantity of the growing stock is declining when judged on a lumber basis and what was originally standing. From the pulpwood standpoint, this decline in quality is of less importance for the pulp mills can and do use lower quality wood.

The wood pulp companies still remain the small consumers of the timber supply compared to lumber and other wood using industries. This, however, is small comfort to those depending upon pulp and paper for livelihood.

Wastes

Waste, both in the logging and the primary conversion of the wood must be cut down, and much more integration accomplished if we are to reap the maximum benefits from our forest lands.

The reduction of waste and greater utilization are not easy problems to solve either technically or economically.

Every visitor to Europe, to Scandinavia in particular, is impressed by the wood using industries and the many products made therefrom. The high cost of oil, grain and molasses, makes the use of wood sugar a necessity. A more closely controlled economy and possibly the absence of anti-trust laws are among the reasons why others have been more aggressive than we in these fields.

Sweden and Finland have been very ingenious and much of their war time subsistence was derived from wood. Some products were war babies and have since been discontinued while others have become permanently established.

The foundation for the Swedish wood, lumber, wood pulp, or for buildsive forest management. Wood is sorted according to its best use, plywood, lumber, wood pulp, or for building products. Much of the saw mill waste is used for wood pulp. The balance of the waste is converted into wood sugar, and charcoal and the residual lignin is used for industrial fuel. Wood sugar is used for alcohol, fodder and yeast, and many other chemical products, such as vitamins, and hormones. In fact, Egon Glesinger believes, in "The Coming Age of Wood," that in wood we have the answer to most of the urgent feeding, clothing and housing problems of the world.

By-product utilization and waste reduction are consuming a large amount of research time and money in the United States and yet, limited amounts of sulphate turpentine, tall oil, vanillin, alcohol, and a small amount of lignin plastics seem to be the only products currently manufactured on this continent. How profitable they will be under normal conditions remains to be proven.

Any consideration of potential future requirements, therefore, must consider reduction of waste by improved operations and better utilization.

The Forest Service Waste Survey has gone into considerable detail, covering the various wood consuming industries.

The logging waste charged to the Pulp and Paper Group exclusive of bark was as given in *Table VI.*

The logging waste in the North and South is of minor importance so far as percentage is concerned. A great deal of this waste is impossible to use for normal quality products. If it has any value, it will be as a chemical raw material.

After the logs are delivered to the pulp mill, barking, cleaning, sawing, and chipping are the next normal operations. In each of these steps waste occurs. These wastes are estimated, according to regions, to be, stated in *Table VIII.*

From the report,[3] it is stated that all waste can be used as fuel, *Table VII* which for all practical purposes is correct. The percentages to the total drain are North 5.75 per cent, South 4.5 per cent, Pacific Northwest 9.05 per cent. These figures appear to be low for normal operations; however, they are probably explained by the fact that in 1944 standards of paper quality were lower due to the war. Wastes will decline as advances in wood cleaning and full log chipping become more common.

The summary of waste, excluding barking and pulping solubles, for the Pulp and Paper Industry is in *Table VIII.*

From this record, the Pacific Northwest has a real objective to work on. With the improvements now installed in the pulp mill wood rooms, various

[3] Reappraisal Report.

TABLE VI

Logging Waste, Exclusive of Bark, Charged to the Pulp & Paper Group

	Total Parts of Trees Left in Forest	Total Trees Destroyed in Forest	Total Logging Waste
		Millions of Cubic Feet	
North	45.1	6.6	51.7
South	42.2	10.6	52.8
Pacific Northwest	110.8	4.3	115.1

This waste compared to total drain of all timber results in the following percentages:

	Total Drain	Total Waste	% Waste in Logging
North	677	51.7	7.65%
South	1,044	52.8	5.05%
Pacific Northwest	309	115.1	37.02%

Source USDA

TABLE VII

Waste in Pulp Mill Wood Preparation

Millions of Cubic Feet

	Slabs & Coarse Material Total	Sawdust and Fines Total	Total Waste can be used as Fuel
North	21.0	18.0	39.0
South	20.0	27.0	47.0
Pacific Northwest	14.0	14.0	28.0

Source USDA

TABLE VIII

Total Wood Waste from Forest to Peeling Operation

Millions of Cubic Feet

Region	Total Pulpwood Drain	Logging & Manufacturing Waste	Percent Waste in Logging & Manufacturing to total Drain
North	677	90.7	13.5
South	1,044	99.8	9.6
Pacific Northwest	309	143.1	46.3
Total	2,030	333.6	16.4

Source USDA

TABLE IX

Logging and Primary Manufacturing Waste, 1945

Millions of Cubic Feet

Product	Total Commodity Drain	Total Waste	Waste % of Drains
Lumber	6,711	4,567	68%
Pulp and Paper, tree to pulp mill	1,306	324	24%
Tree to pulp, excluding bark			74%
Hewed crossties	363	254	70%
Veneer	391	259	66%
Cooperage	175	125	72%

Source USDA

pre-logging and salvage techniques now in use, this loss is considerably lower. Further improvement is bound to result as the second growth smaller timber is used, eliminating sawing, splitting and defective wood.

While wood waste in logging and preparation for pulping is a sizeable quantity, it is very small compared to the losses in processes, most chemical processes dissolve from 40-60 per cent of the original wood. These dissolved substances present serious disposal problems in some types of mills and in some locations.

One of the reasons for the rapid increase in the quantity of sulphate pulp produced is that use is made of a chemical recovery system wherein the non-cellulosic materials can be burned for fuel.

The sulphite process, as normally used with calcium base liquors, shows promise of having a recovery process whereby the dissolved substances can be burned. The development of the sodium, ammonium and magnesium base processes is directed to this end.

To focus attention on the size of the problem, it is estimated that every year there are 8 million dry tons of pulp mill waste available for some unknown use. Some of this is being burned as fuel. Some is valuable fiber lost in processing upon which active recovery measures are being taken. The balance is the industry's main unsolved stream pollution problem.

Comparisons by percentage, of all losses by various wood using industries are given in *Table IX*.

TABLE X

Distribution of Privately Owned Forest Lands

Ownership	Millions of Acres North	South	West
Farm	61.0	69.0	9.0
Industrial and other	78.6	98.0	29.4

These holdings are further divided:

Region	Millions of Acres* Small	Medium	Large
North	118	6	16
South	122	22	23
West	21	5	12
Total	261	33	51

Source USDA

Small—less than 5,000 acres

Medium—5 to 50,000 acres

Large—over 50,040 acres

*Includes non-operating acreage.

Future Resources

There is no doubt but that there are ample lands available to supply any projected future demand for wood, and still not encroach upon other land uses. The solution to future ample supply is one of the most complex problems facing this country.

The forests are one renewable raw material which we have. The raising of wood can be simply stated as a long-term farming project; the length of time required varies from 15-50 years depending on the region, but unlike normal agriculture, returns even of a minor nature take up to 15 or more years, to grow and be realized.

The problem thus is to make these returns profitable from a long-term investment standpoint. Complications are added by the weaknesses in fire and insect control, lack of crop insurance, uncertainty of taxation, states' rights, financing for improvement and maintenance, and the means to live while the crop is growing in the case of the small owner. To this may be added various political pressure groups made up of well intentioned, but often misguided citizens.

Nevertheless, the knowledge, and a great bulk of the know-how, and planning are available, and ready. The spark necessary to bring the opposing factors together in a spirit of compromise, still appears to be lacking. Time is shorter than we realize. Wood at least for lumber will not be the plentiful commodity to which we have become accustomed. Of the 224 million acres held by small owners, only 4% of this acreage is controlled by those having the necessary means and interest to properly work them. Medium sized owners are preserving the productive capacity 8% of their holdings, while the large owners are managing 33% of their land holding in the better class.

Farmers have as a general rule made little progress, followed in ascending order by the other small owners, lumber companies, and pulp companies.

While this progress by the lumber and pulp companies is noteworthy, it must be encouraged still further because, somehow, the program for improvement of farm and other small owner's holdings has failed. Possibly lack of money on the part of the owner, and lack of sales appeal, are the principal reasons.

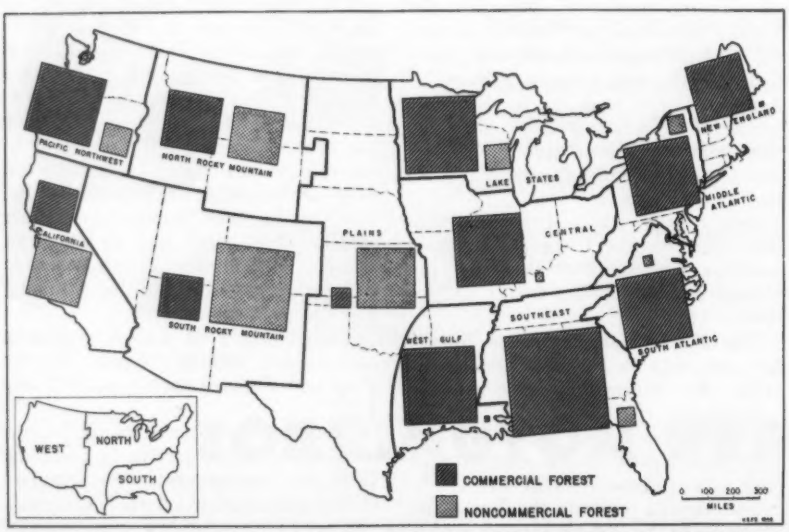
Of our 345 million acres of privately owned lands, the Reappraisal Report shows a varied ownership. This is demonstrated in *Table X*.

Thus we find 75 per cent of private lands held in small acreages of which 53 per cent is farm owned. It is estimated that there are about four million small lot owners.

The Forest Service in making their survey set up cutting standards. These standards in 1945 were:

1. *High-order cutting* requires best type of harvest, which will build up quality and yields to the full productivity of land. A sound, sustained-yield, long term program.

2. *Good cutting* must be made in



DISTRIBUTION OF THE FOREST LANDS OF THE UNITED STATES BY REGIONS

accordance with good silvaculture, the land must be left with desirable species in condition for vigorous growth.

3. *Fair cutting* is the beginning of good practice to maintain a reasonable stock of desirable species.

4. *Poor cutting* leaves land with limited means of reproduction, the removal of all merchantable timber and removal or damage to minimum size trees, with deterioration of preferred species.

5. *Destructive cutting* leaves land without timber value and no means of reproduction.

The results show that as a group, small land owners, who own 75 per cent of the forest land, are very destructive; 25 per cent use fair, 4 per cent use good or better practices. Of the medium class owners, 61 per cent use fair and 8 per cent use good or better practices. Of the large holders, 39 per cent use fair and 29 per cent use good or better practices.

The pulp and paper industry is very conscious of the growing shortages, and many mills have acquired or are acquiring ample forest resources. New mills are spending large amounts of capital for this purpose and formulating cutting programs based on the most intensive sustained yield practices. However, the cost of such a program is tremendous, so that it is limited to the larger, well financed organizations.

The Forest Survey in 1945 shows that about 15 million acres were owned by the pulp companies. In 1948 this was definitely increased to 19 million acres. Some sound judges believe that it may actually be 25 to 30 million acres in 1951. Most of this land is in large holdings, in fact several companies own one million acres and at least one has two and one-fourth million acres.

Strangely enough, farm forestry is the only branch which receives federal and state assistance on a general scale, as provided by Clarke-McNary and Norris-Doxey Laws and many state acts.

Private groups have been active in reforestation for years, preaching the gospel of raising wood as a crop. Their efforts have been successful, considering the limited funds and areas in which they can work. Many of these are sponsored and large parts of their funds are supplied by the pulp and paper companies. "Trees for Tomorrow," "American Tree Farm Movement," "Keep America Green," are worthy examples of what can be and is being done by private capital. However, as worth-while and successful as the programs are, still more means must be devised, as they can only cover a small part of the urgent need.

In projecting the normal need for

wood of the pulp and paper industry in 1944 into consumption in 1950-55, it is interesting to note that these goals were reached in 1948. From the forestry standpoint short time predictions are of little value, except as starting points. Thus estimates are made on the basis of demand in the year 2,000. It is assumed that the population will stabilize at about 167 millions at[4] that paper and paper board will have reached its saturation point. The estimated consumption will be 250 pounds of paper per capita or 21 million tons, while paperboard will reach 275 pounds or 23 million tons yearly. Thus a projected combined consumption of 525 pounds per capita and 44 million tons will be required. This is double the production of 1948. There are indications that this figure may be too low.

[4] The Reappraisal Report.

To manufacture this quantity of board and paper will require 40 million cords of wood. The actual drain in 1944 was 13,661 million cubic feet; the estimate for the year 2000 is 15,576 million cubic feet. The saw timber drain in 1944 was 53,893 million board feet, the estimate for the year 2000 is 62,508 million board feet.

In order to be reasonably safe, growth must reach 20 million cubic feet yearly, about one-third more than is currently being grown.

As has been stated before, the problem has tremendous magnitude, is of extreme complexity, but it must be solved, and solved soon, if we are going to meet the future's demand.

Conclusion

The problem resolves itself into three questions according to the United States Forest Service:

1. *How to achieve good forestry under private ownership?* Here the pulp companies are making excellent progress and achieving outstanding results.

2. *How to protect the public interest in poor-chance forests that are not readily succeptible to good management by their owners?*

This is the heart of the problem as it concerns 75 per cent of the forest area, owned by people generally unable to finance good management or to wait for the long term return.

3. *How to build up the public forest so that they may contribute more, as they must, to our national supply of timber?*

To the three above should be added the question:

How to achieve integrated utilization of wood on a profitable basis?

A review and change of the status of forest lands withdrawn from production should also be made, in order that they may be managed to increase their productive rate, recreational facilities, water shed protection, and esthetic value.

The Pulp and Paper Industry is very conscious of its responsibility and is doing its share or more, in practicing sound management, in research toward higher yields, waste reduction, better utilization and integration.

Many solutions to the forest problem have been advocated among them are various forms of compulsion. It would appear that all interested groups could work out the answers whereby all would profit, each in his own way, without the use of strong bureaucratic police power.

Preparation of Wood

Harold J. Arnold[1]

With the Great Northern Paper Co., Madison, Me. from 1922 to 1929; Maine Seaboard and St. Regis Paper Co., Bucksport from 1930 to the present time.

Introduction

In this paper it is proposed to deal primarily with the description of the process of preparing wood for both groundwood and chemical pulp manufacture. Some description of the equipment, reasons for use, and, finally, some indication of the costs involved will be included.

Flow of Wood

There is presented in *Figure 1* a rough flow diagram of the wood room now in operation at the St. Regis Paper Co.'s mill at Bucksport, Maine. It is probably the only one in existence having exactly the lines of flow of materials, and sequence of operations, shown since it is doubtful if any two woodrooms are exactly alike. Wood rooms vary considerably in lay-out detail but are nearly all alike in the operations performed therein. It may be assumed, therefore, that the operations and sequence shown in *Figure 1* may be considered representative of other operations. After all, the main objective of any wood room is to prepare clean, bark-free logs for grinding and/or uniform chips of the proper quality and dimensions for chemical pulping. Since essentially the same bark, dirt and defects, such as knots, exist on logs throughout the world, with variations due to specie, it follows that the tools for preparing the logs should be essentially the same.

A description of the flow of material through the wood room is in order. Considering *Figure 1* at the upper left hand corner, the wood enters the room via cable and chain conveyors. The wood is directed through the barking drums onto a sorting conveyor where any wood with bark still remaining on it is returned to the barking drums by means of a return conveyor. The barked wood continues on past the splitter, the hand barker (rotary knife barker), the "Woodpecker," and the chippers. As the wood passes these, dry, rough and knotty wood, as well as wood that is too large for the chippers or grinders in the groundwood mill, is then thrown off and split or hand barked. Oftentimes both operations are required. Wood with rough knots is handled at the "Woodpecker." The accepted logs are either taken off at the chippers or sent on to the grinder room, which, incidentally, finishes the treatment as far as logs for the grinders is concerned.

After the wood is chipped the chips have fallen to a floor below, where they are carried by conveyor belts to a bucket elevator which raises them

[1] Wood Room Supervisor, St. Regis Paper Co., Bucksport, Maine.

again to the operating floor level. A conveyor belt delivers these chips to the head end of two selective chip screens which are usually operated in parallel. The screens separate the chips into "oversize" (slivers and large pieces) "acceptable" (proper size), and "sawdust" (fine material too small for use in cooking). The acceptable chips are delivered from the screens directly to the digester room chip lofts or silos, as the case may be, by a series of belt conveyors and an elevator. The oversize chips are carried by a belt to a crusher where they are mainly broken up into acceptable size and then returned to the chip screen.

The waste from the barking drums is carried by water to a bark screen (not shown but located on the floor level beneath the barking drums) where some water is taken out by passing through a revolving screen equipped with perforated plates which allow water to pass but hold back the bark. The bark plus other waste is carried to the back presses, where more water is removed by pressure, and then the pressed waste is carried by belt to an incinerator and burned.

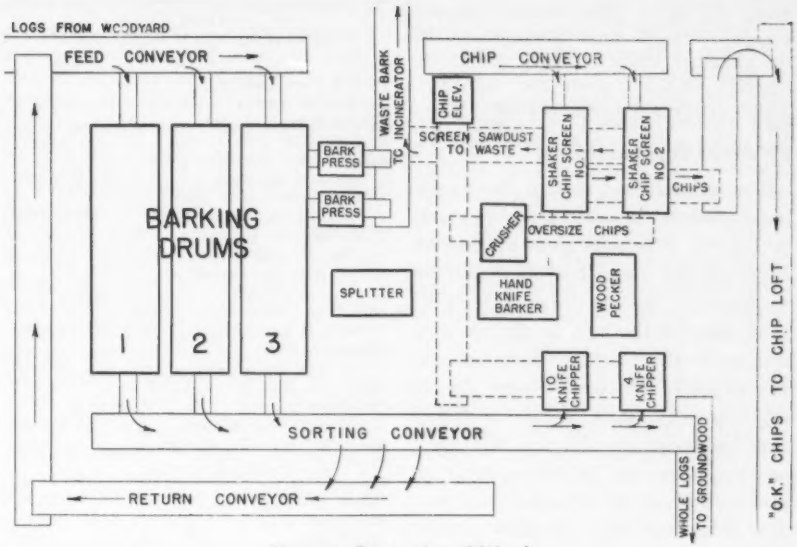


Figure 1—Preparation of Wood

Details of Equipment

(1) *Barking drums.* In the Bucksport mill, there are three barking drums. One is a "V" bar type while the other two are of the solid type. All three are of the so-called suspended type. That is, they are suspended in chains with overhead drive.

The drums are 10 feet in diameter and are 30 feet long. They are each driven by 100 horsepower motors which are geared down from 865 to 8 revolutions per minute.

The purpose of the barkers is twofold in that they serve to remove bark from the logs and also provide a place for washing loose dirt from the logs.

(2) *Splitter.* The splitter is the horizontal type and is used to split those logs which have too large a diameter to fit the chipper or grinders. Wood that is seamy and hollow is split so these imperfections may be cut out on the hand barker.

(3) *Hand barker.* This barker is used to clean rough, dry wood as well as any wood that has been split and found to have back seams.

This barker is a revolving disc having six heavy knives fastened to the disc in such a manner that they take very little bark off at a time so as not to waste too much good wood. This disc is set in a frame with only the upper half of the disc, and hence three knives, showing. The log is placed by hand on a table in front of these knives and forced against them as they revolve, thus cutting away that wood which contacts the knives. It is a very dangerous piece of machinery to work around, and has to be well guarded.

(4) *"Woodpecker."* This machine is used to clean knotty and seamy wood. It makes use of a revolving, cutting head that may be lowered into a log placed in a horizontal position on a tray below it and which quickly cuts away the knot or seam.

(5) *Chippers.* The chippers used are two different types, a four-knife and a ten-knife. The four-knife chipper has a 90 inch diameter disc which travels at a speed of 257 revolutions per minute. It is driven by a direct-connected, synchronous motor, rated at 225 horsepower. The knives are ground to a 40 degree level and are bolted to the disc in such a manner that the knife edge protrudes out beyond the disc to whatever distance is necessary. This distance is the setting which governs the length of the chip produced.

The ten-knife chipper has a 72 inch disc traveling at a speed of 257 revolutions per minute. It is also direct-connected to a synchronous motor which is rated at 225 horsepower. The knives are ground similar to the knives of the four-knife chipper and are bolted to the disc in like manner.

(6) *Chip screens.* The chip selective screens used are of the shaker type. The trays are seven feet and six inches wide by eighteen feet and six inches long. The top tray has rectangular holes perforated in the plate. These are 1 inch by 1-15/16 inches in size. The holes on the bottom, or sawdust, tray are 3/16 inch in diameter. The screens are each actuated by a ten horsepower motor which is connected by a belt to the screen.

The top and bottom trays are connected together by an eccentric which has a three inch "throw" that causes the acceptable chips and sawdust to fall through the perforations in the top screen. The oversize chips pass across that screen by virtue of this shake, as well as a slight incline of the screen, and are deposited on a conveyor and delivered to a crusher. The accepted chips pass across the face of the lower tray and are dropped onto a conveyor which delivers them to the chip storage. The sawdust passes through the smaller perforations of the lower plate and is delivered onto a belt which takes it to the waste conveyor that goes to the incinerator.

(7) *Crusher.* The crusher is made up of a series of 20 discs which are one and one-fourth inches thick and are 20 inches in diameter. These are fitted to a shaft in such a manner that three revolving fingers may be placed between each disc. When the crusher is in operation these fingers whirl and break the oversize chips that they contact. Space relationships with the casing do not permit the chips to pass until they have been reduced to approximately acceptable size or smaller. This crusher is driven by a 30 horsepower motor at a speed of 1165 revolutions per minute.

(8) *Bark presses.* The bark presses are of the plunger type. That is, the wet bark enters at one end of a restrictive chamber. A plunger moves forward and forces the bark toward the exit end of the increasingly more restricted chamber. Of course, as this bark passes through this chamber and if forced into an increasingly smaller volume it under goes a pressing action which results in water being squeezed

from the mass. The water removal escapes through small perforations in the chamber while the bark passes on through and off onto the conveyor which delivers it to the incinerator.

Estimated Equipment Cost

The approximate cost of the equipment used in the wood room is given in *Table 1*. The costs given are merely approximated estimates, it should be emphasized, but are shown to give some idea of the cost of the massive equipment necessary to carry out the operations of the wood room. As an addition to the table, it may be stated that approximately 19 men per crew and two crews per day are required to process 300 cords of wood per day. The labor cost also becomes a considerable factor.

TABLE I
ESTIMATED EQUIPMENT COST

Item	*Cost*
Barking drum (solid) weight 32 tons	$20,000
Barking drum ("U" Bar) weight 20 tons	$20,000
Barking drum suspension chain 200 feet per drum	$7.00 per ft.
Barking drum traction wheels 8 wheels per drum	$80.00 each
#111 Chain for conveyor 6000 ft. required	$1.89 per ft.
#4124 Chain for conveyor 1500 ft. required	$2.04 per ft.
Belts, 6 ply for conveyor 4000 ft. required	$5.50 per ft.
Chipper, 8 knife 15 tons, 88 inch disc	$14,000
Motor, 225 H.P., 257 R.P.M.	$7,000
Chipper, 4 knife 12 tons, 90 inch disc	$12,000
Motor, 225 H.P., 257 R.P.M.	$7,000
Crusher	$2,800
Hand Barker	$1,600
Splitter	$4,000
Bark Press	$8,000
Chip Screen	$5,000
Cost of wood per cord from car to wood room	$2.80

Conclusion

It may well be stated that the operations of the wood room need constant supervision both from operational and safety standpoints. The careless operator not only can allow wood to pass that definitely should be further cleaned but he also may, by careless operation, endanger the safety of not only himself but others.

It can be seen that large scale, expensive equipment is involved. The success of the sales force of the company may often be traced to the fact that the supervisors and men of the wood room crew are operating this equipment in a proper manner and are carefully providing for its maintenance with the consequent result that clean, highly-saleable paper was available for this sales force to sell. It is easy to be careless in the wood room and cause waste and quality losses.

The Wood Room

John Lewis

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Introduction

The wood room is the first department that the wood finds inside the mill. Previous to that the wood has been procured from the forests and has been driven, in rivers, or carried by rail, boat, or truck and been deposited in the yard of the mill or on conveyors leading into the wood room. The typical large piles of wood that are stored in the yard of a pulp mill are a familiar sight to those who live in the vicinity of a mill or have passed by a pulp producing mill.

It would be the ideal situation if there were no need for a wood room. If the logs of pulpwood could be cut and cleanly barked in the woods and delivered to the wood grinders in the groundwood mill, or if it were possible to chemically pulp these logs in this condition, as whole logs, it is certain that the pulp mill operators would be greatly pleased. However, such is not the case. It is true that grinders in most instances do use the whole log, which in this region is a four foot log, but there are other grinders which accommodate only two foot logs and therefore, require sawing the four foot stick into two logs. There are other areas that cut a longer log in the woods and these must be cut to proper length. For chemical pulping, it is necessary that the wood be reduced to chips so that the cooking chemical may easily penetrate into the innermost parts, between the fibers, and dissolve the encrusting lignin that cements these fibers together as the tree grows. Oftentimes it is not possible to bark the logs in the woods because the peeling season only lasts between the months of April and August and any peeling done by hand in the woods becomes a most costly operation at any other season of the year when the wood must, nevertheless, also be cut. Finally, and not the least important, is the fact that the logs inevitably become bruised in transportation and dirt becomes lodged in those bruises by subsequent handling. Dirt is always present in and around the knots and imperfections of the wood. This dirt becomes a problem when it is allowed to get into the process and although screens are always provided to remove it, it is always the soundest policy not to permit any more of it to enter than is possible and the best opportunity to carry out this policy is in the wood room.

The operation of the wood room is constantly a compromise among: 1. Quality of production; 2. Quantity of production; and 3. Cost of production. By this it is meant that to secure the highest quality, dirt-free chips, for instance, it inevitably must be true that a complete cleaning job must be done in removing bark and dirt, knots, oversize splinters, and sawdust. That, in turn, means that a smaller weight of chips per unit weight or volume of wood entering the room will depart from the room. It also means that much more work must be done on the logs by a considerable amount of hand operation, and it follows that the cost of producing that quality work must

increase per unit weight or volume of chips produced. Of course, there are mills in which this high degree of quality is not imperative and the quantity of output may increase and the cost decrease at the expense of the quality of pulp produced from that mill. As one visits from mill to mill, he is struck with the different degree of wood treatment that is being given. It seems that it is a matter of policy to be decided by the different managements as to how much quality must be built into the product in the wood room and how much provision must be made to remove defects such as dirt and bark particles later on in the process.

Wood Room Flow Diagram

In *Figure 1* there is shown a mythical but typical flow diagram of a wood room that is producing both groundwood and a chemical pulp. That chemical pulp might be acid sulfite, semichemical, or any of the alkaline pulping processes such as soda or kraft. It is true that the alkaline pulping mediums can tolerate more bark particles than can the sulfite processes and that any application of this flow diagram is one of degree from one mill to another or from one type of production to the other. It is intended to show a comprehensive wood treatment and it should be pointed out at the start that most mills have less treatment and several may have more. The arrangement of equipment is purely schematic and no attempt has been made to make the equipment relative in size.

Briefly, the logs from the yard may have been previously barked or may be peeled. If the bark is on, a thorough barking action is given in either the drums or the "jet" barker and, if peeled, the logs are usually passed through the drum and given a washing action only. This is the point where loose dirt is most easily removed. The drum barker also provides the opportunity for more dirt to be imbedded into the broomed ends of the log as the logs become splintered because of the pounding action on the ends as they tumble over one another in their passage through. The action of these barkers, as well as the equipment that follows, will be more completely described under a later, separate section.

The logs are then sorted at a special station at which the man in charge selects those logs which have not been completely barked and returns them by conveyors for further treatment in the barkers. Usually a second passage is sufficient to complete the operation but in cold weather, when the bark is frozen solidly onto the wood, it may become necessary to return a log more than once. Of course, such a situation becomes expensive and it is much better to have barked the logs in barkers located in the wood yard outside during the summer months and store them in the large block piles. Then the logs may be passed through the barkers and given a washing action during the winter freezing periods. It is recognized that this is not always possible however, since many logs arrive at the mill during the winter months and must be used before warm weather can thaw them. In such an event the presence of a hot pond is desirable. In this pond, which is maintained at about 150 degrees Fahrnheit, the logs may be stored in passing to the "jet" barker. There, the logs are rid of ice and there is some degree of softening of the bark prior to the action of the jets. This set-up is nearly always used, summer or winter, for the "jet" barker. A similar hot pond is oftentimes set up to accommodate the logs that are to pass through the drum barkers.

The logs next pass down a large sorting conveyor from which those logs that need special hand treatment may be withdrawn for whatever special attention they may need. These treatments may be any or all of the following: 1. splitting, in which large

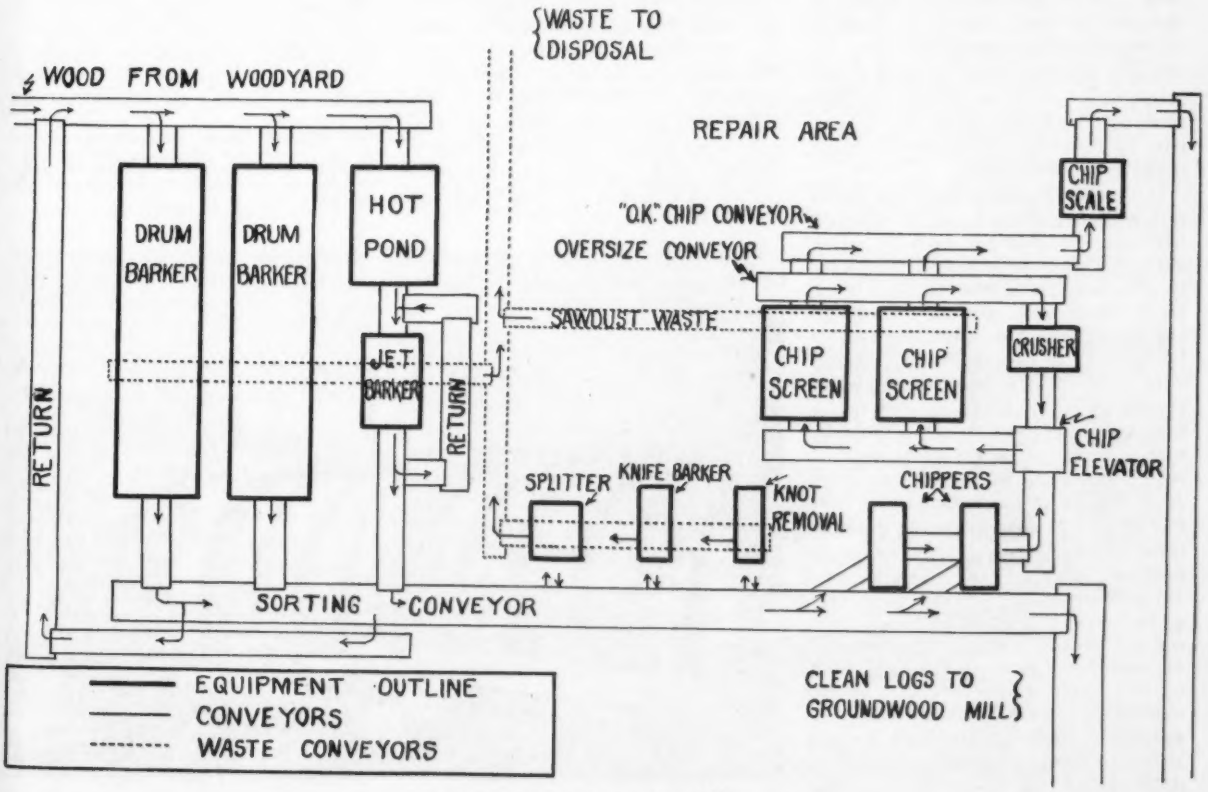

Figure 1—Flow Diagram Wood Room

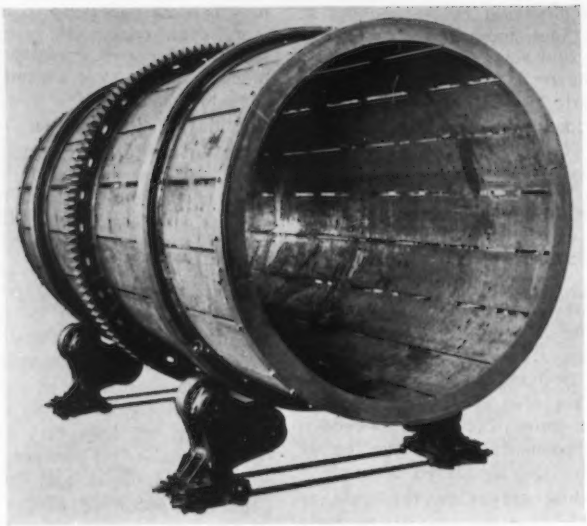

Figure 2—Murray Barking Drum

logs may be reduced lengthwise to a size that can be more easily handled, or in which logs may be opened up so that a seam containing bark or dirt may be more easily reached by the knife barkers; 2. knife barkers, on which the final traces of bark must be removed, or on which surface knots and other surface imperfections may be cut away; and 3. knot removal equipment which includes knot borers, knot saws, "woodpeckers" and the like and on which deep dirt—containing imperfections are cut out.

For a log that is to be used in the groundwood mill, treatment just described is sufficient and it would then pass by conveyor to the block storage in the groundwood mill.

It should be pointed out that up to this point considerable waste material has been removed and must be gotten rid of. This is often merely conveyed to the outside of the building to a truck which hauls it away to a dumping point. It is also often disposed of by burning to the extent that it may even produce some heat for use about the plant. More often the mill operators are satisfied to be able to burn it merely to get rid of it. In the process of disposing of the waste, the bark from the barkers is usually wet from having been submerged in water during the barking process, from removal by hydraulic barking, or it may be wet from washing by streams of water played from hoses into the drums during the barking process. In any event, eventual burning is assured if as much of the water as possible can be removed by mechanical pressing or squeezing. Consequently, bark presses are used before the wet material is delivered to the waste burner. The waste from the hand equipment and subsequent chip screens is considerably drier and is delivered directly to the burner.

Wood that is to be used in the chemical pulping processes must be reduced to chips. This is accomplished in the chippers. Here, the whole log is reduced to chips that are from one-half to one inch in average length along the grain, depending on the process in which they are used. Semi-chemical pulping methods usually dictate a one-half inch chip while the kraft process may use chips up to one inch in length. The sulfite process seems to work most favorably on a three-fourths inch chip.

The chip production from the chippers is by nature a mixture of largely suitable, "O.K.", chips, some oversized chips and splinters and small percentages of "sawdust." The "O.K." chips must be separated from the oversized and the sawdust. The oversized chips are not easily penetrated by the cooking chemical and thus result in reject material at the screens which follow cooking. The sawdust contains little quality fiber and, furthermore and more important, its presence in the cooking digester tends to clog the passages between the chips and cut down on the circulation of the cooking liquor during digestion. Oversized chips and sawdust are, therefore, separated on selective screens. The "O.K." chips pass over a weightometer to record the weight of chip being used. The separated sawdust is sent to disposal and the oversized chips are run through a crusher to reduce them to "O.K." size and are then returned over the screen again.

Drum Barkers*

Figures 2 and 3 show photographs of typical drum barkers. *Figure 2* is a photograph of a barker made by the D. J. Murray Co. The manufacturer's description is given as follows:

"The pulp mill industry considers a 12′ x 45″ two section barking drum as standard. Larger drums and smaller drums can be and are made, but they are very much in the minority. The drum is 12′ inside diameter by 45′ overall length made up in two sections, each section being 22′—6″ long and separated by a gap of one and one-half inches. Each drum section is supported on wheels or trunnions which are carried on roller bearings.

*The equipment pictured and described throughout this section was selected at random and it should in no way be interpreted that the author has selected the particular machine as being superior to any other.

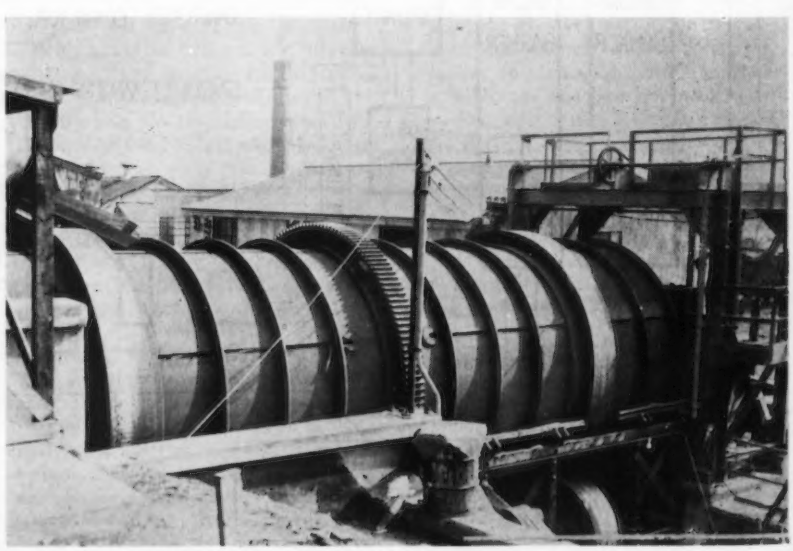

Figure 3—Carthage Drum Barker

These steel trunnion wheels are alternately plain and flanged. The drum is driven through a fully enclosed Herringbone reducer and requires a 200 HP motor at 900 RPM. The actual horsepower requirements are 125-150 HP, but the 200 HP is advised as it is necessary to have this excess power in order to start up the drum.

"The drum rotates at 6 RPM and has a capacity of approximately 20 cords of wood in one hour. Weight of the complete drum is 210,000 pounds."

Figure 3 is a drum barker made by the Carthage Machine Company. The manufacturer's description is given below.

"Size: The drum is built 11′ 11½″ inside diameter and 45′ long. It is supported on two rings 14′ 0″ outside diameter and provided with a cast chrome nickel alloy ring gear about 14′ 7½″ outside diameter.

"Shell: The first 40′ of the shell is composed of six longitudinal plates 1⅛″ thick by 73½″ wide rolled to fit the inside diameter of the rings with 2½″ spaces between. Spacers are welded into place between the plates at the gear, and the plates in turn are welded to the rings to form a heavy tube that will stand the bending and shock strains. On the inside, six tumbling angles, each running the whole length of the drum are welded to the plates. To provide a free bark escape the last 5′ of the drum is composed of 24—1⅛″ plates welded to the outlet end of the drum. These plates are formed to an angle for added rigidity and are in addition girdled by three angle rings 7″ x 4″ x ⅞″.

"Rings: The two trunnion rings are of welded construction, each consisting of a 3″ x 21″ face outer ring to which are welded two riser rings 2″ thick by 6¾″ high. The inner or cylinder rings of 1½″ plate 36″ wide, are securely welded to the inside of the riser rings. After these assemblies are welded together they are stress relieved and finished to 14′ 0″ outside diameter, 12′ 1¾″ inside diameter x 20″ wide on the tread.

"Ten intermediate rings 1½″ x 6″ rolled on edge are furnished in three pieces each for welding to outside of drum.

"Ring Gear: The ring gear is cast of chrome nickel alloy and has 156 teeth, 3½″ circular pitch, 12″ face. It is furnished in accurately mated sections.

"Pinion: A cast steel pinion 3½″ pitch, 25 teeth, 13″ face is mounted so as to mesh with the ring gear.

"Trunnions: There are four supporting trunnions about 72″ dia. cast of abrasion resistant material. The tread is 20¾″ wide and flanged on one side 1¾″ thick by 1″ high to guide the drum against end travel. Steel journals 8¼″ in diameter are pressed into the trunnion wheels.

"Bearings: There are 8 trunnion bearings—mounted in cast iron bearing blocks wedge adjusted on base plates. Four 3 x 3 x ⅝ angles are provided as cross ties to be welded to steel projections on base plates after erecting. These angles run crosswise of the drum to prevent the base plates from spreading apart. Thirty-two setting jacks are furnished, to be left in foundation.

"Drive: For a drum speed of approximately 6 RPM the drive would consist of a 150 HP 1150 RPM motor ———direct connected by flexible coupling to an enclosed Herringbone gear drive with ratio 11½ to 1.——— The enclosed herringbone gear drive would carry a 21 tooth sprocket mounted on the slow speed shaft. This sprocket through———roller chain drives a 54 tooth sprocket mounted on a jack shaft which also carries the main drive pinion described above.

"Weight: Approximately 180,000 pounds, net."

Other companies such as the Chicago Bridge and Iron Co., Fiber Making Processes, Inc. and the Newport News Shipbuilding and Dry Dock Co., as well as others, also build drum barkers and the reader is referred to the trade literature for information concerning these products.

Basically, a drum barker is given slow rotation, about eight revolutions per minute. Logs are fed into one end of the barker. The rotation causes the logs to ride up the side of the drum and then tumble down onto one another. A slight incline toward the opposite end of the drum causes the logs to travel forward. A "dam" at the opposite end keeps as large a quantity of logs as is desirable filling the bottom of the drum. Adjustment of the "dam" level upward retains a larger quantity of logs in the drum. Adjustment of the "dam" downward, of course, has the opposite effect. It is true that after the given level has been attained the output of logs equals the input of logs and production depends only on the feed to the drum and is independent of filled height. It follows, however, that more log to log action is obtained the more logs there are present in the drum up to a point where too many choke the action. The tumbling action in the drum results in the bark being bruised and bumped off the logs. This same action also results in considerable "brooming" of the log ends with a further result of dirt and small bark particles being lodged in these broomed or splintered ends.

The drum barker is effective on either hard or soft wood but is more so on the latter. Production can be reasonably high at an efficient rate for removal of bark. As is often the case, there are special jobs to be done that require special attention or treatment. However, for most routine barking this type of equipment is most commonly used.

Hydraulic Jet Barker

A fairly recent innovation in barking equipment is the hydraulic jet barker. The Allis-Chalmers "Streambarker" is shown in cutaway section in *Figure 4*. That company's description, in part, is given as follows: (This description is an excerpt from a paper presented by Stanley F. Gebarski of that company before the Northwest Wood Products Clinic, April, 1952 at Spokane, Wash.)

"Although there are various types of hydraulic barkers, the method of barking used in the machine I will discuss today is based on a hydraulic principle which, through impact, removes the bark from the logs passing under stationary high velocity jets of water moving at the rate of 300 to 400 feet per second.

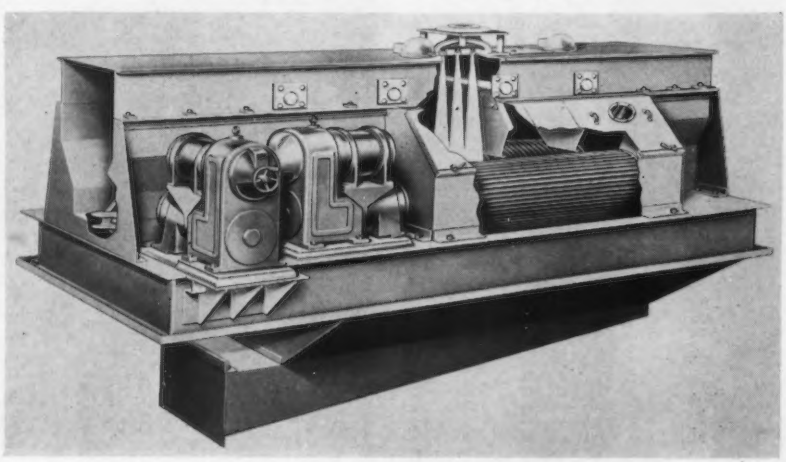

Figure 4—The Allis-Chalmers Steam Barker

Figure 5—Sandy Hill Peppy Peeler

"Essentially, this hydraulic barker consists of two bed rolls 24" by 10' in length which control the motion of the logs while passing under three high velocity high pressure jets of water. One roll has spiral flutes to advance the logs and the other longitudinal flutes to rotate the logs.

"Correct adjustment of these two rolls in relation to each other imparts the necessary forward motion while at the same time rotates the logs so that proper coverage on the logs is achieved by the jets. Hydraulically loaded and cushioned hold down baffles, pivoted at the top of the machine, keep the logs in contact with the rolls but do not retard the forward motion.

"A special type buckhorn chain at the intake of the machine positions the logs properly in respect to the crotch of the rolls.

"A sturdy steel cabinet houses the complete barking chamber and a welded steel hopper is provided below the barking chamber to receive the discharged water and bark and to transport this material to a vibrating screen. Conveyors to the barker and from the bark hopper are not furnished with this machine.

"The current Model "D" is heavier in construction than any of its predecessors, more streamlined, and more efficient. Some of the major advantages of this new model "D" barker are as follows:

1. Maximum log size increased from 18 to 24 inches. (length 4 to 8 feet.)

2. Power cost reduced due to increased capacity obtained from new nozzle arrangement.

3. Capacity in excess of 1500 clean sticks of average 4 foot wood per hour.

4. Maintenance cost greatly reduced. Sectional roll plates were replaced by one piece castings which can be maintained, in place, very readily at a low cost.

5. Standardized bearings, drives, and baffle parts are readily available through usual commercial sources.

"Our barker, because it processes individual pulp wood logs consecutively through the machine must have the barking compartment full at all times to achieve maximum efficiency and eliminate energy loss caused by the jets operating without any logs. To achieve this, the jack-ladder or whatever means is used to deliver the logs to the barker must be properly fed and adjusted so the logs come to the buckhorn chain butt to butt. At no time, however, should the logs be delivered to the buckhorn chain faster than the bed rolls can transport the logs through the barker. If logs are delivered to the barker compartment faster than the bed rolls can advance them, jamming will result with consequent loss of capacity and barking efficiency.

"Various reports have come in to us from mill operators in reference to barking capacities. Based on these reports, we find that there is no so-called average barking capacity. The capacity varies with each mill, species of wood and mean log diameter as well as the condition of wood being handled. In general, we would say that our earlier model barkers are producing on the order of 1000 clean sticks of 4 foot wood per hour. The new model "D", however, is producing in excess of 1500 clean sticks of 4 foot wood per hour.

"Also, a mill in Michigan has reported that improvements were noticed soon after barkers were in production on Aspen logs. On the average, it was reported that quality has improved 28 per cent and production was increased from 6 to 10 per cent. An approximate 30 per cent decrease in wear on plates of disc refiners and a decrease in chemicals used was also noticed. This mill formerly operated on rough wood only.

"To summarize, the outstanding features and advantages of the barker are as follows:

1. Fast continuous, hydraulic barking of pulp wood logs.

2. Barks all types of wood.

3. Logs are cleaner, with complete removal of dozy wood, imbedded dirt, cinders and fly ash.

4. Wood loss is lower than in other methods of barking.

5. Handles logs 4 to 8 feet in length and 4 to 24 inches in diameter.

6. The fuel value of the bark is not impaired.

7. It saves valuable wood room space

Figure 6—Dezurik Knot Borer (Left) and Knot Saw (Right)

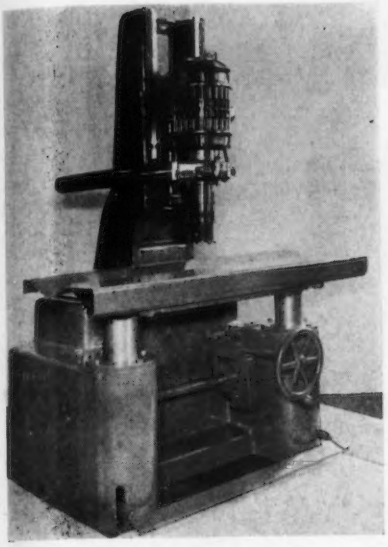

Figure 6-A Dezurik Knot Borer

because of its compactness and simplification of the barking cycle."

The hydraulic barker has been found most useful in barking whole logs on the west coast where the pulp mill is connected with a saw mill operation, There, I understand, the logs are barked, sawn into boards and timber and the remaining edges and slabs are reduced to chips for pulping. It is evident that there the logs cannot be cut into four foot lengths for passage in a drum barker since the boards and timbers must necessarily be longer than that.

These barkers are used for four foot wood in the east and are said to be advantageous where large variations exist in wood size, species, shape and condition, and where high output per unit of space occupied is at a premium. Extreme care in operation and maintenance should be given if best results are to be obtained.

Splitter

The splitter is simply a hydraulic ram equipped wih a splitting, V-shaped, head or it may be a large swinging axehead on an oscillating arm which is driven by an eccentric and thus imparts continuous up and down motion. All the equipment is massive and has a high moment of inertia so that one blow will usually split a four foot stick.

The log to be split is placed into the splitter in such a position that the advancing axehead splits the log into two pieces along the grain of the wood and at the point desired. Logs which are too large to fit into the chipper or are too large to handle manually in the hand operations may be reduced to workable size. If a log has an internal seam of bark or rot, it may be split open in order that it may be reached easily by the knife barkers or other hand operated equipment.

Knife Barkers

There are several types of knife barkers on the market. The Carthage Machine Company, Murray Manufacturing Co., and Sandy Hill Iron and Brass Co., among others, have equipment that is commonly in use.

Depending on the cleanliness requirements of the mill, the final traces of bark may be removed on the knife barkers. There may still be some instances where the knife barker, or the rosser, or the recent Sandy Hill "Peppy Peeler" may be used to do the entire barking operation.

In the disk knife operation, the wood is held against the face of the high speed disk and allowed to rotate against the moving disk. The knives passing by the log cut off the remaining bark. In the rosser or "Peppy Peeler" types of operation, the log is allowed to rotate under a cutting head and the bark is literally peeled off the log. *Figure 5* shows two men at work operating the Sandy Hill Iron and Brass Works "Peppy Peeler."

Knife barking methods, by and large, are wasteful of good wood in that it is difficult, if not impossible, to set knives so that only the bark is cut away even on a perfectly round log. The fact that it is impossible to find perfectly round logs makes it even less likely that only bark will be removed. Knots and other surface irregularities cannot escape being cut away and it follows that good wood must be cut away also. It takes very careful handling to keep wood losses at a minimum.

Knot Removal

Figure 6 shows two men at work removing knots and other surface imperfections that contain dirt. The man at the left is operating a DeZurik Knot Boring machine and the man at the right is using a DeZurik knot saw. More details of these are shown in *Figures 6A and 6B,* respectively. Several companies make similar types of equipment.

Figure 7 shows the type of job that the knot borer does in removing the knots. The type of imperfections removed are shown at left and the loss of wood by use of an axe is shown in the log at the right.

Figure 8 shows a man operating the Williams and Wilson, Limited, "Woodpecker". There the log may be pushed back and forth under the rotating cutting head. Imperfections are removed by manually lowering the rotating cutting head into the portion to be removed.

There are many other variations of these basic principles of removing defects and the reader is again referred to the trade literature or the manufacturer for detailed descriptions.

Chippers

Figures 9 and 9A show a D. J. Murray chipper with details of knife and bedplate construction. There are several companies that manufacture chippers with variations of their own design. The Murray description of this chipper is given below.

"The most popular size chipper manufactured for the pulp industry during the past ten to fifteen years has been the 88", ten knife unit which is equipped with a spout of 18⅜" diameter. To power this chipper, a 400 HP wound rotor induction motor is recommended, being connected to the chipper through a flat belt or a V-belt drive arrangement. Pulley or sheaves

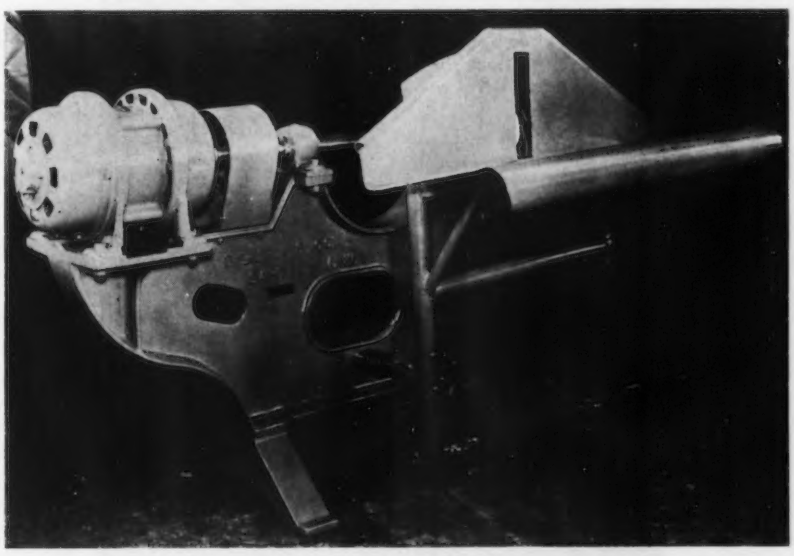

Figure 6-B Dezurik Knot Saw

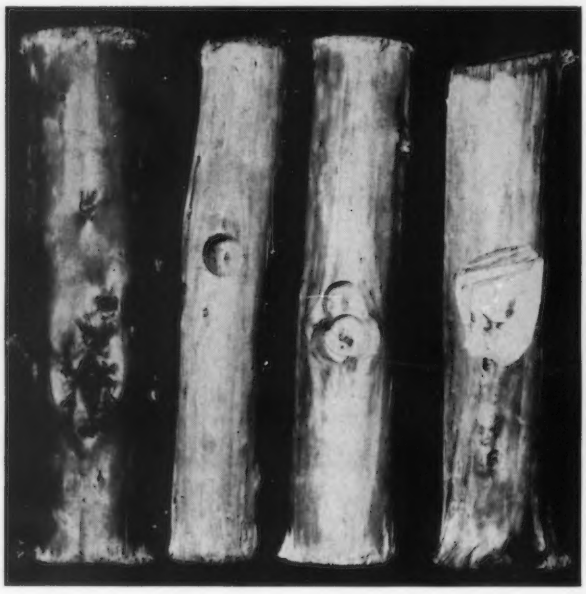

Figure 7—Typical Log Imperfections, and Sample Removal by Knot Borer and by Hand Axe. (From Left to Right)

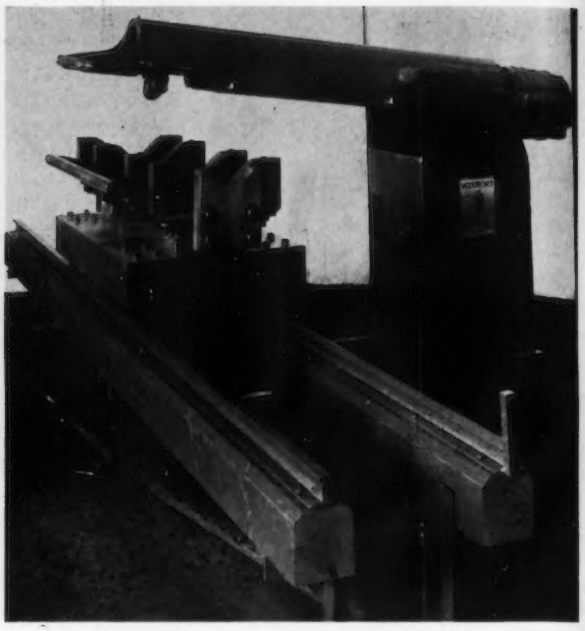

Figure 8—Williams and Wilson, Ltd., Wood Pecker

on the chipper of the flywheel type. Chipper operates at 360 RPM and is equipped with ten knives. Operating at capacity, the chipper will produce approximately 40 cords of wood per hour. This is based on a chip length of 5/8" to 3/4" long. The weight of the chipper is 40,000 pounds."

Logs are fed into the chipper from a spout that is at an angle with the face of the chipper disc. Knives are placed as shown at regular intervals around the face of the disc. As the log meets the face of the disc, a knife cuts into the log and by a cutting action against the bed knife set into the bottom of the spout cuts a full "card" from the log. This card passes through the disc and is broken up into chips on the back of the disc by the action of moving "fingers" that plow into the cards and break them into small chips.

The length of the chips is governed by the distance of the setting of the knives away from the disc surface. The quality of the chips produced is governed by the close tolerance of spacing between the knives on the disc and the knife of the bedplate as well as the sharpness of these knives. More uniform chips are said to be obtained by having multi knives, eight or ten, in the disc. In that case, it is claimed that there is always a knife in the wood and that the log cannot bounce away from the disc face as is possible when four knives are used and there is a split second of time after one knife leaves the log and the next one enters. Uniformity of chip size is much to be desired for optimum chip penetration during cooking.

Chip Screens

There are three basic types of chip screens available on the market from several different manufacturers. The first, rotary type, is the oldest of the three. A rotary screen made by the Carthage Machine Co., is shown in *Figure 10*. In the illustration shown, the chips from the chipper are fed into the near end at the center. The oversized chips pass all the way through the center section and are discharged at the opposite end, usually into a crusher. The mesh of this center screen is such that the "O.K." chips and "sawdust" pass through. The sawdust continues through the second, finer screen but the O.K. chips continue on to be discharged at the end of that screen into a conveyor. The screening action is affected by a rotary motion of the unit. Forward motion is imparted by a slight incline of the screen.

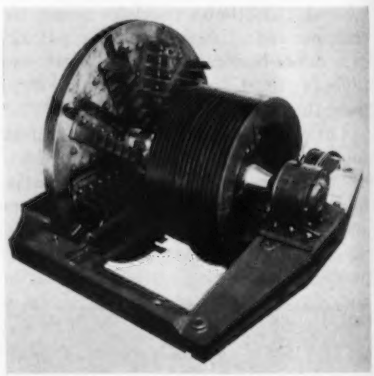

Figure 9-A D. J. Murray Murco Chipper

The other two types are both flat, inclined screens. The variation comes principally in the operation. One, as shown in *Figure 11*, is a vibratory action and the other is a shaker action. In

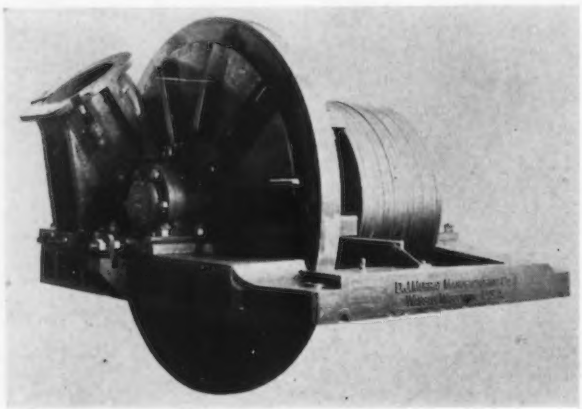

Figure 9—D. J. Murray Murco Chipper

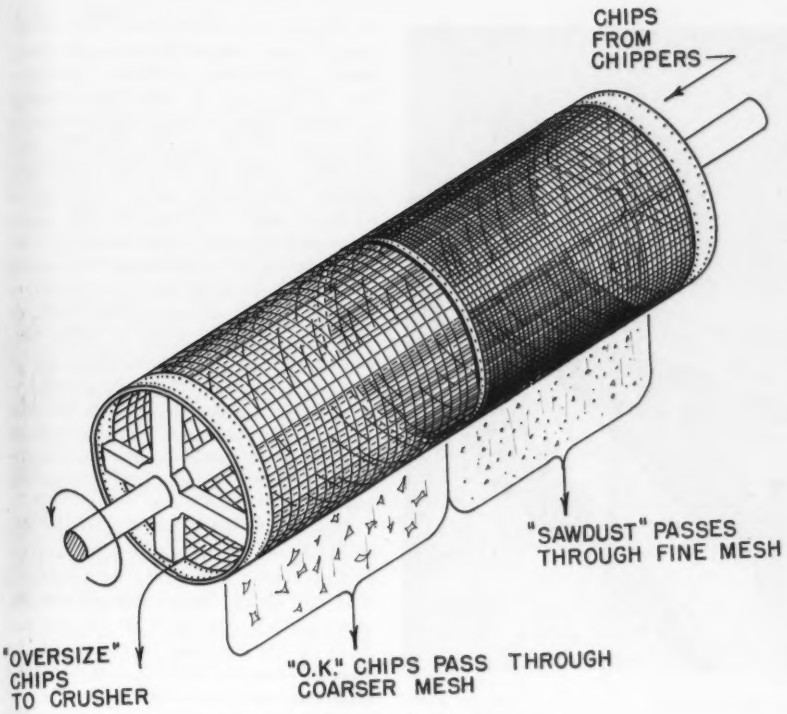

Figure 10—Elements of a Rotary Screen

the shaker type, the screens are given a shaking action by means of an eccentric drive at the head end which causes the chips to bounce around and forward and thus imparts a separating action. The vibratory screen that is shown in *Figur 11*, and which in this case is manufactured by Thomas A. Dillon, Ltd., receives its screening action by a vibration up and down which succeeds in giving each chip an opportunity to bounce up and down many times and hence gives the "O.K." chips and sawdust an opportunity to pass through the screens. Forward motion is also given by the inclination of the screen. As is shown, the oversized chips are delivered off the top screen, the "O.K." chips off the bottom screen, and the sawdust passes through the bottom screen.

Weightometer

In many mills, the chips from the screen are sent directly to the chip loft above the digesters. This, then, completes the operations of the wood room. However, in the mill where an accurate accounting is made of the wood chips that are cooked, a weightometer is used. This device is placed on the conveyor leading to the chip loft and the moving chips are weighed continuously by mechanical integration as they pass over the scale. This provides an accurate method of finding the dry weight of the chips used when combined with a periodic, or continuous, moisture content determination. From the knowledge of the weight of wood leaving the wood room, it is possible to determine the yield of cooked pulp from the digesters and it also provides a means of checking on wood losses by waste in the wood room. A weightometer made by the Merrick Scales Manufacturing Co. is shown in *Figure 12*.

Conclusion

The wood room offers an excellent point of study from the standpoint of decreasing the cost of production. Much emphasis has been placed on the improvement of digester and bleaching yields by small percentages while losses exist in the wood room that may exceed these gains of yield by several per cent.

Losses on the knife barkers may amount to as high as 30 per cent. If a considerable amount of this type of barking is done, that loss may amount to a staggering sum of money in a year's time. If these losses, by careful operation brought about by proper supervision, can be reduced by only a few per cent then a substantial savings can be realized.

Losses of three to four per cent are often experienced in drum barkers due to brooming and bruising. The hydraulic barker has reduced this loss by one half but at the same time has introduced a more costly operation that may or may not be more expensive over-all to the mill. There may well be a barking method developed that can eliminate this loss and yet be accomplished on a machine which is less expensive to operate. Chemical barking methods are being tried but as yet have not been proven satisfactory or economical since they are still in the investigation stage. Chain bark-

Figure 11—Dillon Chip Screen

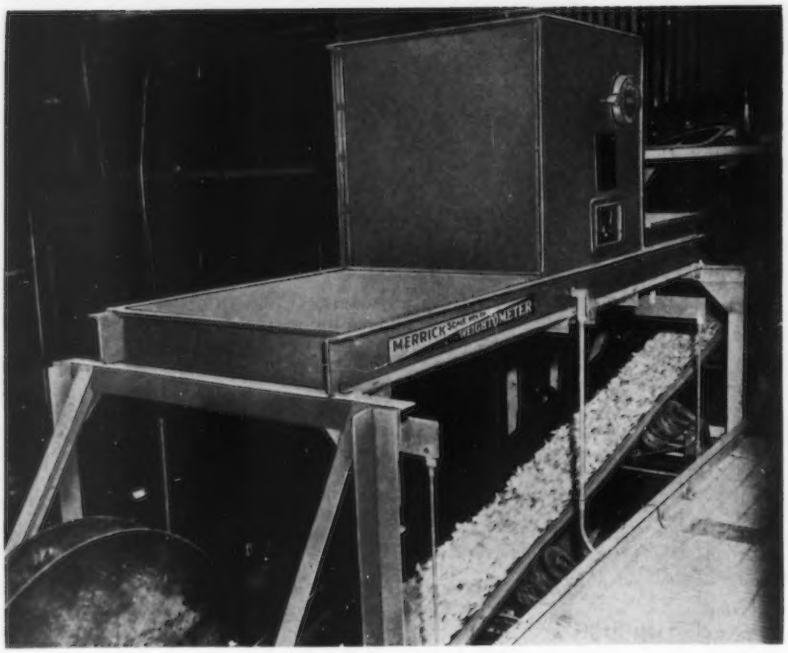

Figure 12—Merrick Weightometer

ers and hydraulic ring barkers have been introduced that have not yet met with popular and probably economic appeal. There still remains the problem of removing bark satisfactorily at low cost and with essentially no loss of usable wood.

Losses up to and exceeding four per cent are often found as a result of chipper sawdust. This appears to be a matter of careful control of the condition of the chipper knives and bedplate. Frequent, periodic selective screen analyses of the chips coming from the chipper will show the amount of sawdust being made and this procedure, combined with an economic study, will dictate when it becomes of more value to shut down the equipment and change to sharp knives. For it can be closely determined how much it will cost to shut down a chipper to change knives in any given mill. It also can be determined at what percentage of sawdust loss, the cost of that loss, and the increased power input to do the chipper, exceeds the cost of changing knives. When that point is reached, it would seem economically sound to shut down and change the knives.

Another factor enters into the desirability of changing chipper knives. It has been conclusively demonstrated that dull knives bruise the ends of the chips as they are cut from the log and that as the bruising is increased the strength and uniformity of the finished pulp are materially reduced.

The solving of these as well as other problems that could be mentioned could well be the object of extensive study in a department of the mill that is sometimes forgotten for the more glamorous problems of cooking and bleaching.

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Manufacture of Groundwood

H. L. Hayes

Graduate from University of New Hampshire, Class of 1905, B.S. degree in Electrical Engineering. He worked for General Electric Co. in tests at Schenectady, and also out of Boston office on construction work. Went to work for St. Croix Paper Co. as electrical engineer in 1911, which position he held until 1936, when he was appointed assistant general manager. In 1945 he was promoted to vice-president and general manager, and also made an officer and director of several subsidiary companies. He was elected a director of the St. Croix Paper Co. in 1949.

Introduction

The manufacture of newsprint in today's competitive market must be done on high speed machines with the cheapest run material that will satisfy the demands of the newspaper publishers. The finished product must have not only sufficient strength to withstand the tension introduced by the paper machine during manufacture but, also, the tension introduced by the presses when the sheet is printed. The surface of the sheet must be smooth in order that it will print properly. These factors are controlled to a large extent by the type of pulp that is used in the sheet.

Naturally, inasmuch as mechanical pulp is the cheapest form of pulp, it is desirable to use as high a percentage of it in the sheet as possible. However, the pulp fibers, being shorter than those resulting from chemical pulping, form a weaker sheet, and a percentage of sulfite, or sometimes kraft, must be added.

Woods Used

In order to understand better the preparation of pulp, and some of the problems involved, let us start with the stick of wood as it is delivered to the mill. Throughout the remainder of the discussion the use of the flow diagram shown in Figure 1 may be found helpful.

In general, black spruce produces the best pulp and the slow growing high land spruce, grown in cold climates, generally has the highest density, producing the best quality of pulp and also the highest yield per cord. The so called density of wood normally runs from 35 pounds to 45 pounds per cubic foot, and the yield averages from 1800 to 3000 pounds of pulp per cord for groundwood, less for sulfite. In some mills, in Quebec particularly, the spruce is so dense that it makes a pulp which produces a hard sheet of paper. It is necessary, therefore, to add a percentage of fir rather than use all spruce. If low land pulp wood is used, the same as grown along the coast of Maine, then it is very desirable to use all spruce to get the highest quality of pulp. Recently a chemi-groundwood process has been developed to use the common hard woods, which may be successful.

Pulpwood for most Eastern mills comes to the mill in four foot lengths, whether delivered by cars, trucks, or driven in the river. The modern grinder is made generally to accommodate four foot wood. Wood for sulfite can be used in most any lengths, but handling by the shippers has held it down to four foot length.

Pulpwood is peeled both in the woods and at the plant. There is a greater tendency to remove the bark of spruce and fir at the plant because it is difficult to get men to peel wood in the woods since this work has to be done in summer months, particularly during the black fly season. If wood is shipped for long distances by railroad or trucks it is desirable to have it peeled to save freight. Hemlock is practically always peeled in the woods because it is very difficult to bark mechanically after it is dried out and also, if river driven, hemlock sinks more quickly than other soft woods. All woods, of course, sink more quickly with bark on. The St. Croix Paper Co. allows three percent sinkage loss but this amount varies with different companies.

Mills in the northern states and Canada that depend on river driven wood build up large piles of pulpwood in the mill yards during the summer to carry them through the winter months. These piles, commonly referred to as "block piles," may contain several hundred thousand cords, which are usually split into a number of smaller piles.

Wood Preparation

In summer, peeled wood goes either directly from the pond to the grinders or through a washing drum and then to the grinders. Rough wood, of course, must be barked before it is ready for grinding.

In the winter, wood generally comes from the block pile and goes through a washing drum. Practically the same equipment is used for washing and for barking. In winter, warm water is used in the washing drum or the wood may be passed through a tank of warm water. It is possible to bark wood in winter but is much more difficult than if the bark is water soaked as it is when it comes from the pond.

There are two main types of barking equipment which are the high pressure water barkers and the barking drums, or so-called "tumbling barrels." The barking drums are of two general types: dry barking and wet barking. With dry barking, the removed waste bark can be disposed of by burning in with little or no trouble. In wet barking, the water must be squeezed out until the waste bark is 60 percent dry in order to burn it satisfactorily. Barking drums are more commonly used in the East than is the high water pressure method because the latter takes a larger amount of power.

Grinders

There are four principal types of grinders used in the United States and Canada which are the Great Northern, the Waterous, the Continuous Chain Feed and the Roberts. There is also a combination of the Waterous and the Great Northern and, too, there are some foreign grinders in use.

The Great Northern and Waterous grinders depend on pressure of wood against stone by pressure from a so-called "pressure foot" which covers the area of the pocket. The pressure on the pressure foot is supplied by water pressure on a piston (or pistons) which actuates the pressure foot. The actual pressure on the wood depends on the ratio of pressure foot area to piston area. In speaking of grinding pressure, it is common to refer to the water pressure on the piston and this may be misleading if the above ratio is not considered.

The Waterous and Great Northern grinders vary the grinding pressure every time a pocket is filled. Consider a two pocket grinder with one grinder per line, when one pocket is being filled the pressure is doubled on the other pocket by a load regulator to try to hold a constant load on the prime mover and also to maintain constant production as nearly as possible. For a certain stone condition the load varies directly as the pressure but production does not vary directly with pressure. The normal pressure on the wood exerted by the pressure foot varies in different mills from 25 pounds per square inch to 75 pounds per square inch but of course this pressure goes considerably higher during the filling of the pockets. Even with a constant feed, such as in a continuous feed grinder, the actual pressure per square

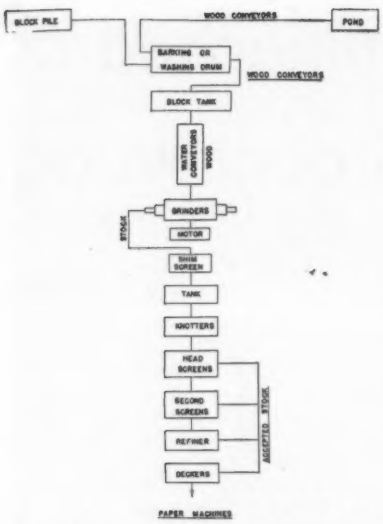


Fig. 1—Typical Flow Diagram—Groundwood Process

inch of wood varies widely because in grinding a round log the area in contact with the stone is constantly changing.

The Continuous Chain Feed Magazine grinder has an endless chain on each side of the pocket. These chains are driven by electric motors and lugs attached to the chains engage the wood and the downward travel of the chains force the wood against the stone. These grinders have practically a constant load since they have only one pocket, and the chains always maintain a constant pressure of wood against the stone. The wood is fed through the top from a floor above. The ease of feeding makes very cheap labor for operating these grinders.

The Roberts grinder has a volute casing around the stone so that the wood is crowded into a narrow opening between the stone and the casing by the action of a ring with teeth on it which constantly rotates around the stone and thus causes the wood to be pressed against the stone.

There are operating advantages in all the different grinders but they all accomplish the same grinding result in practically the same manner, i.e., forcing the wood against the stone. The variation in quantity and quality of pulp depend on: surface of the stone, pressure per square inch of wood, peripheral speed of stone, temperature and consistency of stock in the pit and a number of minor variations.

The stones consist of two major types which are: natural sandstone and artificial. The natural stones are not used to any great extent in the present day four foot grinders. The artificial stones are built up from synthetic grains, called "grit," and are held together by a binder. Artificial stones may be made of one size of grit or a combination of sizes. In our mill we started out using a 60 grit but now have settled mostly on a 50 grit. In both cases these are combinations. We did try one stone having a straight 60 grit but did not like it.

The stones for a four foot grinder are generally fifty-four inches wide but the diameter varies according to the peripheral speed desired. Stones vary from fifty-two to seventy-two inches in diameter. The horse power required varies from 1,000 to 3,000 per stone, depending on tons production and horse power per ton. It is claimed by some authorities that the peripheral speed of the stone should not be over 4,400 feet per minute but many mills run at a much higher speed. There seems to be a tendency to the higher speeds in new installations.

Although the grit of the stone is very important, the marking of the surface of the stone is of primary importance. This, as a rule, is accomplished by running a steel burr across the surface of a stone which cuts grooves to give the desired pattern. The burrs in most common use are spiral No. 8 to No. 12 inclusive, with 1¼ to 1½ inch "leads." The numbers refer to grooves per inch and the "lead" is the amount that the grooves vary from a straight line across the burr. These are generally varied according to the season of the year. It is claimed, however, at least by one mill, that if the wood coming to the grinder room in winter is allowed to warm up so that all frost is removed, summer and winter grinding remain the same. There are three mills that I know which use a so-called "two burr system" such as a No. 8 or No. 10 burr crossed by a No. 2 or No. 4 cut burr. It is claimed for this system that the grooves produced by the No. 2 burr carry stock without regrinding. It is obvious that regrinding does consume more power because if fibers are once removed from the log and if any more work is done on that fiber, more power is required. The finer burrs do the actual cutting of fibers from wood. However, some regrinding seems to be desirable since the real object of burring is to tear the fibers free rather than cut them. Regrinding does tend to crush and segregate fibers and to draw them out. To get a good quality of groundwood requires that wood have around forty-five percent moisture as it allows the fibers to be torn off, rather than cut or broken off as is the case when dry wood is used. In addition to the so-called marking burrs which I have just described, some mills use a fine diamond burr to smooth off the rough edges of the cuts. This roughness tends to produce coarse stock.

How often a stone should be burred is always a good question. Some mills burr on a regular cycle, such as every thirty hours of operation, regardless of the condition of the stone. Other mills determine the condition of the stone by taking samples of the stock from the pit and burring only when examination of the sample indicates it to be necessary. In our mill we burr each stone each day.

The power required ranges from 55 to 80 horsepower per ton of groundwood. It is claimed by some mills that the higher the horsepower per ton the better the quality of the pulp for the same grade of wood but, of course, this is not necessarily true. In the manufacture of newsprint, the general object is to produce as high strength of groundwood pulp as possible to save sulfite. It is necessary, therefore, to balance the cost of groundwood against the cost of sulfite and in that case high horsepower per ton is a big factor in the cost of groundwood.

There are usually two showers on a stone. One is located under the back pocket and the other between pockets. These showers serve the purposes of controlling temperature and cleaning the stone. A thermometer built under the front pocket automatically controls the temperature of the stone by controlling the volume of water from the water showers.

The stone is also kept clean by the stock in the grinder pit, which also has considerable effect on the temperature of the stone. The consistency of the stock in the pit varies in different mills. In the St. Croix Paper Co. mill, consistency of stock will average 3½ to 4 percent and the temperature is approximately 140-180 deg. F. The depth of the stock in the pit, which is controlled by a dam, influences these factors.

Screening

The stock from the grinder pits passes first through a coarse screen to remove large shims which are slivers from three inches to a foot long that might plug the pumps. It then goes through so-called knotter screens which are expected to remove the coarse lumps and large slivers up to three inches long. The stock from the knotter screen goes to the head screens which separate the stock into two classes: accepted and rejected stock. The accepted stock goes to the Deckers for thickening and then to the paper machines. The rejected stock goes to a second set of screens where it is again divided into two classes, accepted stock and rejected stock. The rejected stock from the second screens goes to a refiner, in our case it is a Haug Refiner, which makes a very fine stock that acts as a filler and has comparatively low strength. The stock goes into the refiner like shredded wheat and comes out like oatmeal.

Our stock screens are a rotary type and are equipped with plates having round perforations which are 0.065 inches in diameter. The consistency of the accepted stock is approximately 0.5 percent that results in a large amount of fluid going to the deckers. A later type of screen is now coming into common use from which the accepted stock is as high as three quarters of one percent. This higher consistency is especially desirable because the volume of stock going to deckers will be much less thus requiring a smaller number of deckers and less pump capacity.

In some mills the rejected stock

from the screens is put through a refiner and then it is returned to the first screens. In this case the refiner is expected to make good pulp and the screens reject more pulp, depending on refiners to improve its quality. The screened pulp goes to the deckers for removal of the water and thus increase the consistency to about three to four percent which is the approximate range usually desired for the mixer. The mixer controls the amount of sulfite which is mixed with the groundwood to give the proper mixture for the paper machines.

Control Tests

Newsprint requires a higher quality of groundwood than other grades of groundwood paper because the stronger the groundwood the less sulfite that will have to be used.

The real idea is to produce a groundwood fiber as nearly as possible like a sulfite fiber. All mills have a laboratory for testing stock as well as the finished paper. Some mills are much more technically inclined than others and have a more elaborate system of tests.

Checking the amount of wood coming into a mill is very difficult where wood is driven down a river. It is usually too expensive to actually stack and measure the wood by the cord. It is, of course, a simple job if all wood comes in cars or trucks. One practice is to count the sticks and assume a certain number of sticks to a cord but this is not accurate unless a constant check is kept on number of sticks to a cord. It is comparatively easy to check the wood for the sulfite mill because the chips can be weighed as they go over a belt having a weighing attachment. This is not practical for the four foot wood going to the grinders. In our particular case we have found that our Great Northern grinders run about nine and one-half pockets per cord and we keep a check on the number of pockets ground. We are now trying to develop a system of counting the pockets mechanically as we have found it unreliable to depend on the men to record them accurately.

The quality of groundwood produced is determined largely by taking Canadian Standard Freeness tests and, in addition, Mullen and tear tests from hand made sheets.

The freeness determines the action of the stock on the paper machine wire. In our mill it is taken at each grinder each day and at the mixer every two hours. It is possible to get the same freeness with different qualities of stock so it is usual to determine what freeness suits the paper machines in any particular mill. The freeness should remain more or less constant, assuming the same quality of wood and method of grinding. Another check on fiber length may be obtained from a stock classifier but this is not in common use except possibly for intermittent tests. A stock classifier consists of a set of screens, each screen having different mesh openings. The pulp being tested is passed in dilute suspension through the series of screens in decreasing order of mesh size. The percent of stock rejected by each screen, i.e., unable to pass through to the next smaller sized screen, classifies the stock by length of fibers. This is similar to sorting stone for crushed rock.

The most common groundwood test is the "Blue Glass" and most groundwood men depend on this test as much as any. This involves the visual observation of a dilute suspension of a sample of stock spread out on a blue glass plate. The character of the light fiber is shown up against this dark background. As a matter of fact, the only real test for pulp is how it runs on the paper machines but the pulp tests do act as a guide and are necessary.

Many mills apparently go by Mullen only in determining the strength of the pulp and finished paper but in our mill we go mostly by tearing strength both for handsheet samples of the stock and the finished paper. We have found that Mullen is relatively unimportant, particularly in the finished sheet, if the sheet has sufficient tearing strength. In these days of high speed paper machines it is necessary to use a certain amount of sulfite to run the paper machines efficiently so they automatically obtain the required tear strength from the sulfite.

At the present time newsprint is in such demand that complaints are infrequent, however when there is a surplus supply of paper the complaints will just flow in.

Mechanical Pulping

T. E. Kloss

Mr. Kloss a native of Massachusetts, is a graduate of the University of Maine in Chemical Engineering. He has had a long and successful history in the paper industry. For several years he held important positions in research and operations, while with Spanish River Mills at Sault Ste. Marie, Ontario. He was later Groundwood and Sulphite Superintendent at Mersey Paper Co. where he developed the use of eastern hemlock in the sulphite process. For many years he was General Superintendent of the Maine Seaboard Co. and Ryegate Paper Co. He is now Assistant Manager of Northern Mills of the Hollingsworth & Whitney Co. at Waterville, Maine.

Introduction

The manufacture of mechanical pulp was developed in 1885 when the patents on the wood grinder expired. At the same time the sulfite process was clear of patent rights. The printing press for printing a continuous sheet of paper was ready and demanded a cheaper grade of paper. Water power was waiting to be developed and there seemed to be an endless supply of wood suitable for wood pulp. In the period between 1885 to 1915 both the United States and Canada had built a great many mills. From 1915 to 1930 there was the greatest development of high speed paper machines and high speed printing presses that the world had ever seen. In this year of 1951 the United States mills will produce 26 million tons of paper and paperboard. The production of mechanical pulp in the United States for 1949 was about two million tons. Within the past fifty years, mechanical pulp has found use in other so-called groundwood paper, such as wall paper, and other higher priced coating paper.

The result of all this progress in the paper industry has also brought about the electric motor-driven, automatic magazine grinder and a number of precision built refiners.

Recent developments sponsored by Forest Products Laboratories and others have shown that the mechanical pulping field may soon by broadened into other methods that will have many advantages.

The softwoods such as spruce, fir,

TABLE I
SOME PROPERTIES OF CERTAIN WOODS IN THE UNITED STATES

	Specific Gravity	Shrinkage, %	Bark %	Hardness Side	Hardness End	Cellulose, %	Lignin %	Fiber Length Millimeters
Conifers:								
Spruce:								
Engelmann	0.31	10.4	11.1	240	250	60.5	27.9	3.50
Sitka	0.37	11.5		350	430	60.5	29.6	5.50
White	0.37	13.7	12.4	320	350	60.4	29.0	3.50
Fir:								
Grand	0.37	10.6	9.1	360	420	63.0	27.0	5.00
White	0.35	9.4		330	380			3.50
Douglas Fir:								
Coast type	0.45	11.8	10.6	480	510	59.7	30.3	5.50
Pine:								
Jack	0.39	10.4	9.8	370	380	58.7	28.5	3.50
Red	0.44	11.5		340	360			3.50
White Eastern	0.34	8.2	12.5	310	310	60.0	27.5	3.50
Hemlock:								
Eastern	0.38	9.7	18.9	400	500	54.4	34.1	3.50
Western	0.38	11.9	9.7	430	520	59.6	30.2	4.00
Larch:								
Tamarack	0.49	13.6		380	400			4.00
Western	0.48	13.2	8.8	450	470	57.8		5.00
Hardwoods:								
Ash:								
White	0.55	13.3		960	1010	51.0	26.4	1.20
Basswood	0.32	15.8		250	290	61.2		1.20
Beech	0.56	16.3		850	970			1.20
Birch:								
Paper	0.48	16.2	13.2	560	470	60.6	25.7	1.20
Yellow	0.55	16.7		780	810	61.3		1.50
Chestnut	0.40	11.6		420	530			1.00
Elm:								
American	0.46	14.6	9.6	620	680	58.3	24.3	1.50
Gum:								
Black	0.46	13.9	12.4	640	790	56.7	28.4	1.70
Maple:								
Red	0.49	13.1		700	780			1.00
Sugar	0.56	14.9	13.7	970	1070	60.8	23.2	1.00
Poplar:								
Quaking aspen	0.35	11.5	18.4	300	280	65.5	23.4	1.25
Large-toothed aspen	0.35	11.8		370	400			1.30

and some poplar have been the principle woods used for mechanical pulp. The Herty Foundation Laboratory at Savannah, Georgia, in 1930 to 1934, developed the use of gum wood and several species of southern pine for mechanical pulp. All of these woods, except poplar and gum, belong to the class of long fibered woods. The future is concerned with the use of hardwoods for wood pulp. Mention will be made of wood species showing some of the characteristics that are pertinent to the mechanical pulping process.

Wood Preparation

Wood is delivered in four foot lengths by truck, rail, boat, or is driven by stream to the mill. Some of the wood is peeled in the woods, but, because of the great demand, most of the wood is rough wood. Pulpwood is procured from the company limits or is purchased from small jobbers or larger contractors. Most mills, through their woods department, have wood trimmed and cut to proper length. Large quantities of wood must be stored at the mill and if it is to be kept in storage for more than a year, it would be barked before it is piled. Wood stored with its bark on deteriorates quickly in the summer time due to moisture, heat and the activity of wood borers.

Once the wood is delivered to the wood room for preparation, the main object is to remove the bark, knots with ingrown bark, gum seams and any other dirt attached to the stick. There may be no less than one dozen defects in a stick of wood. Also, there are probably no two sticks that are alike due to the way nature has grown the tree; influenced by its environment, and its general location, such as whether it is in swampy or hilly country.

A modern wood room would include a hot pond for removing ice or frost during the winter months, drum barkers, stream barkers, hand barkers, splitters, and a small slasher or cut off saw. A main inspection conveyor is needed after the stream barkers or drum barkers to sort out the defective wood or final cleaning. Advantage is taken for recirculating partly barked wood through the larger barker devices to save manual labor. Many mills have too few barking units to handle all rough wood. There are still many mills that use two foot grinders for making groundwood and in these plants a continuous slashing program is carried out in the wood room.

Wood Specie

The above program would be the same for any specie of wood up to this point of the process. *Table 1* shows some of the characteristics of various specie of wood. A study of these properties might suggest a method of pretreatment of the wood after previous preparation to make any specie suitable for producing mechanical pulp. Specific gravity, hardness and fiber length are the most important factors which influence yield and quality.

Let us look at the column on specific gravity, which is based on dry weight and green volume for the determination of specific gravity. Looking at white spruce, for example, you have a specific gravity of 0.37 which is not, by any means, the highest of specific gravity of the specie because we have some red and black spruce as high as 0.41. It makes a great deal of difference what specific gravity is used in determining how much of the yield per cord of wood is going to be.

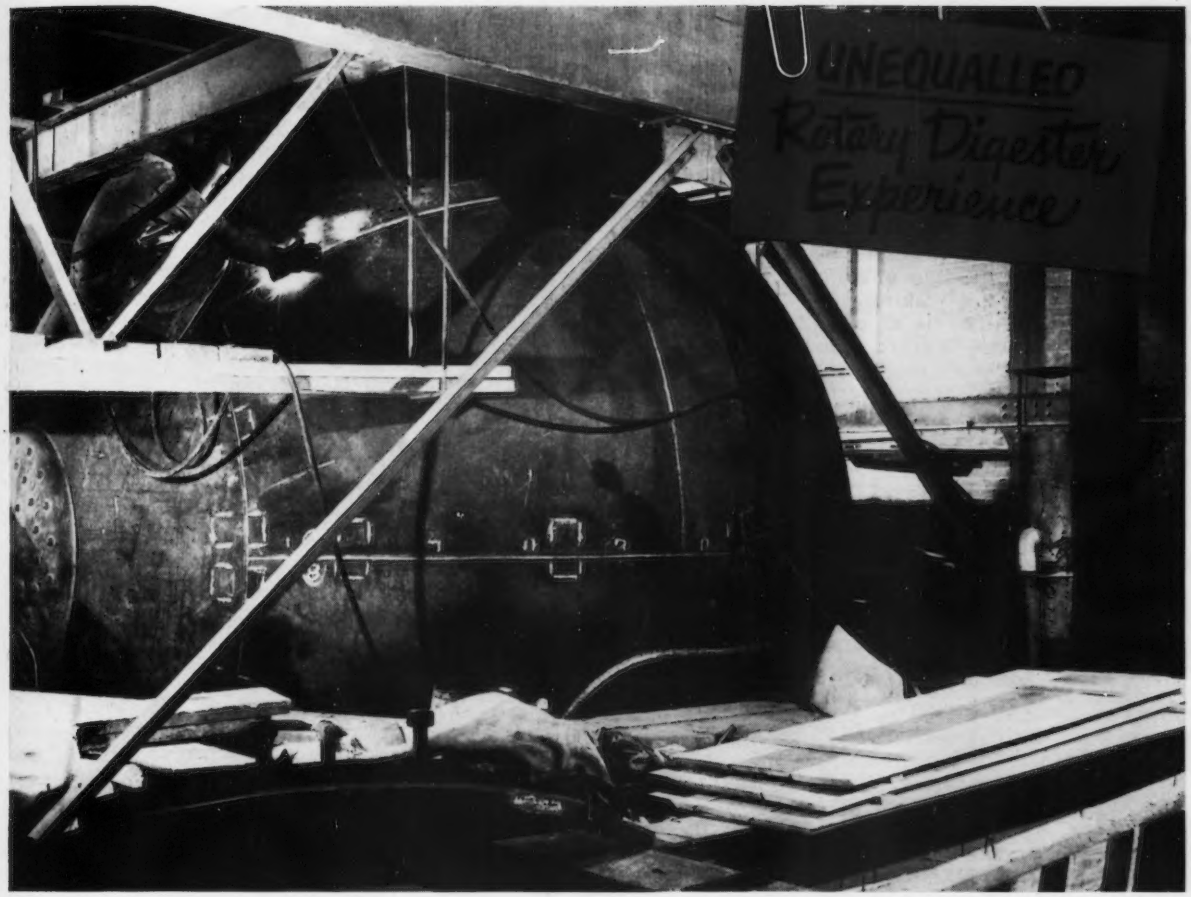
In the next column is shrinkage, by which we mean the shrinkage of the wood volume independent of the bark. The next column is the bark percentage, which is obvious. These things have to do with how much you are getting for your money. Can you justify some of those disadvantages in the consideration if using hardwood for pulp making?

As far as hardness is concerned, it has a lot to do with mechanical pulping and possibly the penetration of chemicals into the wood although pilot plant tests on chemical pulping have shown that hardwood cooks very satisfactorily with the right base.

Now the cellulose figures are reasonably in line, and, correspondingly, the lignin figures. Those two quantities are grouped together because outside of certain water solubles, nothing is taken out of the wood by grinding or by any other mechanical process that is not affected by chemical or semi-chemical treatment.

The fiber length is of importance because it is a question of whether you can find a way to utilize the finer and shorter fibers in the manufacture of paper. When you consider that we are grinding, refining, and cooking this wood and we do come up with certain lengths of fibers, it is well to remember that paper is not all made up of long fibers. Paper is made by a combination of fibers of various lengths, or by even utilizing a supplementary process that will alter the fiber length.

There is one item that is not included in this table. A matter of color goes along with some of these woods like maple, hemlock, birch, and possibly oak. The problem of color with respect to the General Electric brightness, either unbleached or bleached, is rather important, but since we do have bleaching processes we might be justi-



BIGGS Solid Stainless Rotary Digester Installed at West Virginia Pulp and Paper . . .

SEMI-CHEMICAL pulping of hardwood chips at the Mechanicville, N. Y., plant of West Virginia Pulp & Paper Company, called for additional digesting facilities. West Virginia engineers, after considerable study, selected three 16-foot Biggs Globe Rotary Digesters because they wanted to be sure of getting thorough wetting and mixing, a high concentration of cooking liquor at lowest steam requirements.

The first of the three digesters to be installed was made of solid stainless steel with a 2½-inch fiber glass insulation. It has a 2143 cubic foot capacity, thoroughly cooking four and one-half charges of 25,750 pounds each of hardwood chips — approximately 60 tons of chips per day.

Because of metal shortage the remaining two digesters were built of plain steel, and of the same capacities. West Virginia, like most leading paper mills, is preparing for increased semi-chemical production by installing globe rotary digesting equipment. And, like leading mills everywhere, they have specified Biggs Globe Rotary Digesters into the construction of which goes the unmatched experience of the world's largest builder of this kind of equipment.

Write for your copy of new digester bulletin just off the presses.

THE BIGGS BOILER WORKS COMPANY

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fied having a little darker wood to start with and then taking care of it at the comparative little extra cost.

There are several units of measure of wood. The one most commonly used is a *cord,* 128 cubic feet. There is also a *cunit* which is 100 cubic feet. The southern mills have a unit specific to their territory. You will hear a lot about the content of a pile of wood. If you have rough wood in a pile you may have a cord of wood by measure but you really do not have a cord of wood that you can say is all solid wood. The range is somewhere from 95 cubic feet of solid wood per cord down to 83 cubic feet. You have to take into consideration what yield you are getting for the price you pay for a cord of wood. Individual mills have developed tests and standards for evaluating the wood they use.

Wood Reserves of Maine

I thought it would be interesting to pick up the last Maine Report on the quantity of wood that we have in Maine. If you ever go to any other state that is connected with the pulp and paper business you will want to know something about the forest reserves of that state if you are attached to a pulp producing company.

According to that December, 1946, Maine report, the estimated amount of standing timber in this state is shown in *Table II.* (500 board feet are equivalent to a cord of wood.) The estimated amount of standing timber in this state is 2,930,000,000 board feet of birch, maple, and beech which is suitable for lumber. If you divide the figure by 500, you have the equivalent of about 6,000,000 cords of wood. The others are given directly in cords except pine which is approximately equivalent to eight million cords.

It can be seen that we are talking about a considerable quantity of hardwood that is nevertheless small compared with the spruce and fir quantities. Just remember that last year the State of Maine produced one and one-half million cords of wood. (This is only the pulpwood production; and to meet the demand it was necessary to get another 500,000 cords of wood from outside the state. These figures are shown to encourage the use of new specie of woods for pulp manufacture in whatever process they may be applied.

Groundwood Process

The groundwood process is built around a series of wood grinders which reduce the pulp sticks to groundwood fiber. The wood grinder is a machine fitted with a large abrasive stone mounted on a heavy shaft. The dimensions of the grinder stone are designed so that the width is greater that the length of a pulpwood stick, since all wood is ground with its longitudinal surface against the stone. The diameter of the stone is limited to safe peripheral speed based on the range of speeds of the water wheel or motor driving the grinder wheel. The grinder stone is built into the lower section of a casing so that the stone may be submerged in its own stock at all times. The frame or casing of the grinder provides one or more pockets or magazines which contains the wood to be ground. These pockets are equipped with hydraulic or mechanical pressure devices that may exert 30-60 pounds per square inch on the wood which rests on the stone surface.

The capacity of wood grinders varies widely from 5 to 30 tons depending on the size, design and power provided for the grinder. The power required per ton of groundwood varies with the condition of the stone, the wood and the grade of pulp desired, and the general policy with regard to use of power.

The more modern magazine type of grinders would include, the Waterous continuous, Waterous magazine hydraulic, Great Northern and the Roberts grinder. All of these have automatic control of load and speed and are capable of high production. These grinders are also equipped with stone sharpening lathes with traveling carriage that supports the sharpening tool commonly known as a burr.

The burr is a section of a cylinder of about four inches diameter. The burr is supplied with a number of variations of patterns which includes the spiral with varying pitch and number of teeth to the inch, the straight cut, the thread and the diamond. There are several types of tooth. The spiral burrs can be ordered either right or left hand thread. The application of the correct burr for any given condition of grinding for a specified grade of groundwood is the key to the process.

Auxiliary Equipment

Auxiliary equipment needed for the process are coarse and fine screens, thickeners, fresh and white water pumps, stock pumps and refiners.

Groundwood pulp from the grinders is screened at low consistency so that coarse woody particles and dirt are rejected and later recovered through refining. The acceptable stock is thickened and ready for the paper mill or outside market. The extracted water, called white water, is used again in the process in practically a closed system.

In recent years groundwood pulp has been bleached to a high brightness with peroxide or hypochlorite chemicals whenever the brighter pulp is in demand. The bleaching process is completed before the pulp leaves the groundwood mill.

The capacity controls would include the use of governors for uniform grinding conditions, stock consistency regulators, and detailed records of grinding operations.

The general operating practice in the United States and Canada is the so-called hot grinding; high consistency grinding at a temperature of 150 to 185 degrees Fahrenheit. This method gains some advantage in power saving and provides satisfactory pulp for most grades of groundwood. The power consumption would range from 58 to 68 horsepower per ton.

The Scandinavian practice calls for cool grinding; low consistency at a temperature 120 to 150 degrees Fahrenheit and calls for power consumption of 70 to 85 horsepower per ton.

In the earlier days of pulp grinding, natural stones were used. In recent years, artificial abrasive stones were developed that were built to withstand the higher temperatures. The stones are now designed with prescribed combinations of grit sizes. Grits with aluminum base are egg shape while those of silica base are sharp and irregular. There is a growing tendency to favor the aluminum base grit.

TABLE II

WOOD RESERVES OF MAINE:	
Hardwood suitable for lumber: (Yellow Birch, Maple, and Beech)	2,930,000,000 bd. ft.
White Birch suitable for Novelties	2,170,000 cords
Poplar	2,532,000 cords
Hardwood Pulp Wood	27,200,000 cords
Spruce, Fir and Hemlock Pulpwood	42,914,000 cords
Pine suitable for lumber and boxboard	41,113,000,000 bd. ft.
PULPWOOD PRODUCTION OF MAINE (1950) (Rough wood basis)	
Spruce and Fir	1,020,767 cords
Hemlock	132,411 cords
Pine	54,667 cords
Hardwood	263,551 cords
Poplar	85,793 cords
(Total)	1,557,189 cords

Flow Diagram

The sequence of operations just described in general is shown in the flow diagram of *Figure 1.* This diagram is only typical of many that may be found in practice.

The wood is taken from preparation in the wood room and is sent to storage and measuring before it is placed on the grinders. The detailed description of the grinding process is given in the paper by Mr. Warren Daniell of the Great Northern Paper Co.

The first treatment the pulp receives after it leaves the grinders is on the sliver or bull screens. Here, large slivers of wood are removed and sent to refiners to be reduced to pulp size and returned to the system or other special processing.

Once the slivers are removed and you have reasonably clean stock, it is then pumped to the vibratory coarse screens. They are not employed in all mills and are not shown in *Figure 1,* but those that are used generally send the rejects directly to the refiners from which they are returned to the system. The accepted stock goes through the fine screens. Incidentally, you are going to hear a great deal of the so-called Jonsson vibratory screen as well as others that are offering the same principal. Sometimes these Jonsson coarse screens are very helpful in coarse screening and for bark.

The accepted stock from the coarse screens is then passed through a series of so-called fine screens which may be of the conventional flat-vibratory type but more often are of the rotary type. On these screens further separation of acceptable pulp and smaller coarse particles takes place. The rejected material is again sent through the refiners while the acceptable stock is further processed into wet laps on wet machines or is thickened for paper machine storage.

The white water, so called because of the small, white, fine material it contains which is removed at the wet machines or thickeners, may be returned directly back to the system as make-up water. Some water must be purged from the system. This is passed through a save-all which is a filtering machine. There are several types on the market, designed to remove the fiber before the water is finally permitted to go to the sewer.

Such a white water system as just described is called a closed system. No groundwood room would be economical if you had to use fresh water completely nor would the pulp be of good quality.

Having a closed system brings out another point that is not very often considered from the standpoint of the process right through the paper mill. 75% of the power applied generates heat, the warm stock and white water carried through the mill to the paper machines.

Quality of Product

There are a number of tests that may be applied to groundwood pulp as a guide to the operation both in the pulping process and the paper mill and also to subsequent physical tests made on the pulp and paper.

To the experienced pulp operator, a frame with a blue colored glass with a sample of thin pulp suspension provides a working guide to several desired characteristics.

The Canadian freeness tester is a standard measure of drainage rate of the pulp and these tests provide a common denominator for rating the pulp as "free" or "slow" pulp in terms of so many degrees of freeness. There are conditions, however, that give a false freeness due to presence of short bundles of fiber and these conditions upset the drainage on the wire of the paper machines. This latter condition may be detected on the blue glass.

The Bauer-McNett classifier gives a fair idea of quality of groundwood and the coarseness modulus that is derived from combination of fiber lengths is of some value. It is another way of describing the quality of groundwood for a certain grade of paper.

Groundwood with a Canadian freeness range of 160 to 250 is bulky and is suitable for box board, liner, wrapper, and paper dishes.

Groundwood with a Canadian freeness of 85 to 95 is suitable for newsprint and wall paper.

Groundwood with a Canadian freeness of 60 to 80 is a very slow, dense pulp and is suitable for coating stock, book, magazine and other groundwood papers.

Records

No groundwood mill would be successful without a definite system of control which is standard practice in most mills. Routine testing for freeness, consistency, strength, moisture in lap pulp and sample inspection sheets are the order of the day and are performed as quickly as possible as guide to the operation.

Other records of immediate value would include the pressure gauge readings on the grinders, temperature of grinding, speed of stone, stones sharpened, burr used, speed of grinder shaft, quantity of wood used per grinder and such information on water wheels or motors as would indicate the input power to the grinder, as well as the total power used daily in the mill. The

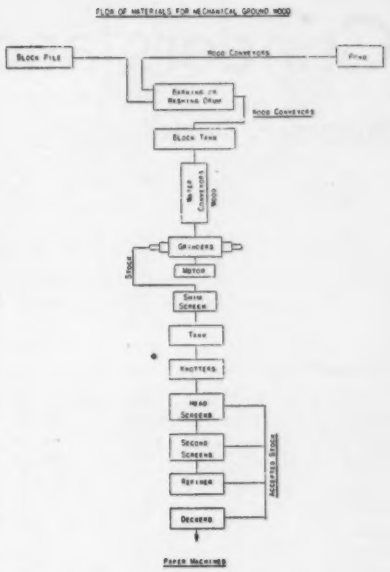

Figure 1

determination of daily yield of pulp per cord is of importance as well as screening and white water losses. Of more general nature, grinder stone and wet machine felt life, cylinder wires, number of burrs used, total wood used, and total production made matters of accounting records. Shipping records are also kept.

Conclusion

There are other processes for mechanical pulp that are new which border on the field of chemi-groundwood and semi-chemical pulp, requiring use of various refiners, which are not described in this paper. Likewise, the processes for bleaching groundwood by reduction or oxidation methods have been left out of this discussion. Details of grinders and manipulation of sharpening tools have been left for a later paper on the subject.

The purpose of this paper has been to present a general idea of the process, and with modern developments, to indicate the future possibilities for the manufacture of mechanical pulp by one method or another. Some of the barriers against certain wood specie, such as initial color, hardness, and fiber length, may be removed by bleaching, pre-treatment, and by a change in method of pulping.

The wasp and the silk worm suggested the groundwood and rayon process, but the spruce bud worm, the elm and birch beetle have taken away many trees. It is well to watch the worm's eye view of these matters, but persistent scientific treatment of the subject will keep the industry in this state supplied with wood.

Grinders and Grinding*

Warren F. Daniell

Graduated Dartmouth College 1922. Entire business career has been spent with the Great Northern Paper Co. Starting in the apprentice foreman training course in 1922, he has held the following positions: groundwood superintendent, East Millinocket Mill; groundwood superintendent, Millinocket Mill; superintendent, Bureau of Tests; and since 1950 he has been chief engineer for the company.

Introduction

There is a general impression in many places that the manufacture of groundwood pulp is a very simple thing. A few years ago I was visiting a pulp and paper mill where there were both a sulfite and a groundwood mill. The manager was showing me around the mill explaining in some detail the things of interest. When he got to the grinder room he volunteered, "We have a lot of young technical men in the organization but none of them are interested in working in the groundwood mill. They think the process is so simple that they would not be interested." You run into that attitude because it looks like a very simple thing to put a stick of wood on the stone and see pulp come out ready, after screening, to be made into paper.

It is like a lot of things that appear simple. When you get interested and study all the variables that it is necessary to control to produce a uniform, good quality of pulp, you will find groundwood is fully as complicated and has as much interest as chemical pulp. Of course, in the manufacture of newsprint, which is the main product of the Great Northern Paper Company, groundwood is the important item of the furnish to the extent that it makes up about 85 percent of the pulp that goes into the paper.

The speaker last week covered the general subject of groundwood which is such a large subject that he recognized he could not give much detail to each part. The groundwood mill as a whole includes wood preparation and grinding as well as screening and thickening the pulp to prepare it for the paper mill.

I am limiting my talk this morning to the subject of grinding. This will include:

1. A description of the different types of grinders in use today.

2. Pulpstones and the troubles which developed as grinders were made larger and which, to some extent, have been solved during the last 25 years.

3. Treatment of pulpstones by burring. Other grinding variables.

4. A brief discussion of the testing of groundwood and the extent upon which the tests can be relied.

Types of Grinders

Pocket Grinder. We will take up first the different types of grinders which are in use today. We will take them up more or less in the order in which they came into use in the industry. The groundwood process was developed around 1856 to 1860 and there were a number of small grinders which were in operation in the 1860's.

The very earliest model, which was not long in use, was a grinder in which the wood was held against the stone by means of jack screws similar to a car jack. As the wood ground away the operator kept tightening the jack screw in order to maintain a somewhat uniform pressure. Stones at that time were driven by water wheels and the speed of the wheel would be determined by the amount of power absorbed on the stone face. The only control of speed in those days was by the ear of the operator. He could tell by the sound whether the grinder was speeding up or slowing down. When he heard it speed up he would take his wrench and tighten up the jack screws a little bit, which put a braking force on the stone. The wheel and stone would begin to slow down. If he had tightened the jack screws too much the grinder slowed down too much or stopped. It was a continuous operation for the grinderman or even a low production unit to attend to the jack screws.

Of course people very quickly realized that there was a better way of controlling the grinder speed. A hydraulic cylinder was developed to apply constant pressure to the wood and the pressure was adjusted by a hand operated reducing valve throttling the water supply to the cylinders. Because the early grinders were driven by water wheels the logical variable by which to control the pressure was the speed. A governor was required which would increase the pressure as the water wheel speeded up. The simplest and first attempt at automatic regulation was by means of a centrifugal pump which was belted to the grinder shaft. As the grinder speeded up the pump speed increased and that gave more pressure in the water line to the grinder cylinders, and tended to slow down the grinder to the proper speed.

Figure 1 shows diagrammatically the first hydraulic grinder. The stone was about four feet in diameter and a little more than two feet wide. There were usually three pockets, sometimes four. Many grinders of this type are operating in small mills today. The wood was pushed in through a door in the side of the pocket, one stick at a time. The wood in the pocket had to be arranged in a manner so that the foot plate pressure applied on top of the sticks would not bind or wedge the sticks against the sides of the pocket. When the wood wedged it took a higher than normal cylinder pressure to get effective pressure of the wood against the stone, because part of the pressure was absorbed in friction on the sides of the pocket. Under these conditions the wood is compressed more than normally. This dense wood grinds to a different quality of pulp. Too many plugged or partly plugged pockets in a grinder room can change the quality of pulp enough to upset the operating conditions on the paper machines using that pulp.

Pulp quality will also vary with the speed of the stone. The efficiency of a water wheel will likewise vary with the speed. If it is designed to run at one particular speed, a speed higher or lower than that speed will give less power from the same amount of water and consequently less pulp. Speed variation was therefore important.

As I have mentioned, the first effort to control the speed of water wheel driven stones was by supplying water to the grinder cylinders through a pump which was driven by a belt from the water wheel shaft. It was soon apparent, however, that while this was an improvement over constant pressure there was still too wide a range of speeds. The next improvement was a governor which would multiply the variation in pressure resulting from the speed changes of the pump belted to the waterwheel shaft. The pressure from the grinder shaft driven pump actuated a reducing valve on a high pressure water line. A five pound differential in pressure might have resulted from 10 r.p.m. increase on the grinder shaft belt driven pump. The same speed change with the governor

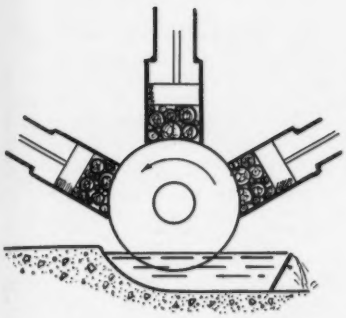

Figure 1—Three pocket grinder

system could increase the grinding pressure by 50 pounds. The quicker increase or decrease in grinding pressure resulted in a more constant speed of the water wheel and pulp stone.

As electric drives came in to use and were applied to grinders the problem of speed regulation was solved. The problem had changed. Now it was a question of load regulation. When a fixed amount of power is purchased on a peak load basis it is economical to use it all continuously. A governor was developed which would vary the pressure as the load on the driving motor varied. It increased the pressure in the grinder cylinders when the load dropped below the set point and it lowered the pressure when the load was above the set point.

The small grinder shown in *Figure 1* was developed in the 1870's and grinder design was not changed appreciably until the 1920's. This was the standard grinder for half a century. There were minor improvements in the method of mounting the pulpstone on the shaft, in strengthening different parts, in the water control valves, and in the sharpening lathes. Higher grinding pressures were used with more power input per stone and therefore more production per grinder. But essentially there was no change in the original grinder design from 1870 until 1920.

After 1920 larger paper machines were built, paper machines were speeded up and a great many new mills were built. Most of the new groundwood mills were built in Canada because of cheap water power and an abundance of spruce and balsam fir, which are the best woods to make good quality groundwood. There was a great deal of interest in larger grinder units which would have more capacity and which would require less operating labor than the standard two foot grinders. Enlarging the standard design two foot grinder to a four foot width was tried; but the operating labor was more, rather than less, because placing four foot lengths of pulpwood into the pockets was a back-breaking job.

Waterous Hydraulic Magazine Grinder. The first successful large grinder was the Waterous Hydraulic Magazine grinder. This is shown diagramatically in *Figure 2*. The stone face was wide enough to grind four foot wood and was also larger in diameter to permit wider pockets. This gave more grinding surface which permitted more power to be applied without excessive unit grinding pressure. The magazine extended to an upper floor. Pulpwood could be dragged or rolled across the floor from a storage bin and placed in the magazine without being lifted. With the same effort, a man could handle several times as much wood as he was able to handle operating two foot grinders. Another saving was in wood waste. When a four foot stick is sawed in the middle the sawdust removed is waste. This may not appear to be much of a loss, but with a sharp saw in good condition one half inch of wood is cut to sawdust which is 1 percent of a 50 inch stick. If a mill is grinding 200,000 cords of wood a year, and many mills grind that much, the loss would be 2000 cords. At $25 a cord, the annual loss would be $50,000. The saving in labor cost is several times as much.

This grinder was successful and many installations were made in the new Canadian mills. Unit capacities were increased from ten tons or less up to thirty tons a unit. Production per man hour of operating labor increased from one to three tons. However, the stone cost per ton was much higher than for the small grinders, because of more stone breakage, and because it was very difficult to find natural sandstone formations from which large pulp stones could be quarried. Pulpstones will be discussed in detail later after we have finished discussing other new types of grinders.

Referring again to *Figure 2*, you will note that the Waterous Hydraulic Grinder takes up a large space. The pockets are horizontal and the assembled pocket with hydraulic cylinders takes up fifteen feet from the center line of the shaft or thirty feet for the full grinder. The magazine is twenty feet high and the wood loading and storage floor is level with the top of the grinder and must be of heavy construction.

Warren Chain Grinder. Another type of grinder developed soon after the Waterous Hydraulic Grinder was the Warren Chain Grinder, *Figure 3*. Four heavy chains inside the high magazine were used to pull the wood against the stone face. This was the first large grinder which did not use hydraulic pressure to hold the wood against the stone. These chains were geared down to run very slowly and had spike points on the side of the chains in contact with the wood. The column of wood in the magazine was gripped by the spike points and pulled down against the stone. The speed of the chains was varied by a governor to maintain the desired pressure on the stone face.

Soon after the Warren grinder was developed in this country the Voith grinder was developed in Germany.

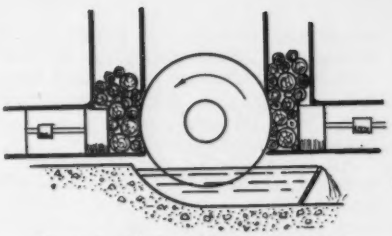

Figure 2—Waterous hydraulic grinder

The major difference in design was the use of lugs on the chains in place of the spike points.

Whenever a new grinder has been developed the manufacturers have advertised in glowing terms the advantages of the new grinder over those in existence. They have invariably stated that the new grinder could produce more and better pulp at less power consumption. Actually, in practice, the quality of pulp and the power required is almost independent of the type of grinder. The variables in wood quality in different mills, if disregarded, may indicate that one grinder is better in one place and another type of grinder in another mill. Accurate testing under identical conditions has indicated that as far as quality and the related horse power per ton of pulp are concerned there is very little difference between the various types of grinders. Many grinders have been sold however on the basis that they would make better pulp at lower power consumption per ton.

The Great Northern Paper Co. purchased and installed Warren Chain grinders in the Madison mill in 1924 and expected to get better pulp at lower power consumption per ton in addition to lower labor cost and wood saving. The Warren grinder was the first grinder which was designed to maintain continuous uniform grinding. All the pocket type grinders release part of the load by backing off the cylinder pressure to get another charge of wood into the grinder pocket. Looking again at *Figure 3* you see the chains which come up on the outside of the magazine and down on the inside pulling the wood against the stone. There are four chains, two on each side of the magazine. Very strong gears and sprockets located at the bottom of the magazine drive the chains. The speed of the chain is controlled by a variable speed motor operating through the reduction gearing. The speed of the chain drive motor is controlled by a governor to maintain the set load on the grinder drive motor.

One disadvantage of the chain type grinder is a much higher maintenance cost. At the present time we are replacing chains. When you think of a chain you may think that a new chain for your bicycle does not cost much. One grinder chain today costs $3000 and there are four chains on each grinder. These chains are subject to corrosion due to steam and vapor in

the grinder casing. It is impossible to maintain sufficient lubrication to prevent wear. Although the chains may last from ten to twenty years they have to be replaced, and it is an expensive replacement.

An advantage of this type grinder is that it occupies less space than the hydraulic type, in which the cylinders stick out on each side in a horizontal direction. In some old mills and some new mills the space available is the deciding factor in the choice of this grinder.

Great Northern Grinder. I will refer now to the Great Northern Grinder which is shown in diagrammatic cross section in *Figure 4*. A picture of it is in *Figure 5*. The other four foot grinders which I have previously mentioned were built early in the 1920's. The Warren grinders were installed in the Great Northern Paper Co. Madison mill in 1924. We were not satisfied with their operation. The chains broke, the capacity per unit was less than we had hoped for, and the saving in horsepower that had been promised for the same quality of pulp did not materialize. We did not install them in our other mills although we realized the need for four foot grinders to get the labor saving, wood saving, and increased capacity. After studying the existing grinders, the organization under the leadership of the president of the Great Northern Paper Co., William Whitcomb, designed a grinder which suited our own conditions. We had water wheels already installed to drive the existing two foot grinders. The water wheels in the East Millinocket mill were installed on 25 foot centers and it would have been a very expensive job to change the location of the water wheels. We needed a grinder which would fit into the available space.

We did not want to build a second story on the grinder room to provide a wood storage and charging floor, which would be necessary for the chain type grinders. The Great Northern Grinder was designed to fit into the existing space. Looking at *Figure 4* you will note that the design is somewhat similar to the lower part of the Waterous Hydraulic Grinder, but the magazines are only two feet high instead of 18 feet high. These short magazines hold enough wood to fill the pocket once. To occupy less space the pockets are tipped at a 15 degree angle from the horizontal. This also made more working room close to the grinder pit. This made it easier for the operator to clean the grinder pit with the long shim hook, the tool used to remove thin slabs of wood from the grinder pits. When the shims are allowed to collect in the grinder pits they retard the circulation of pulp which is necessary to maintain a uniform temperature. Lack of circulation will cause localized hot spots which will damage the stone and sometimes cause the stone to break. All the other new grinders had been bothered with this trouble when they were first

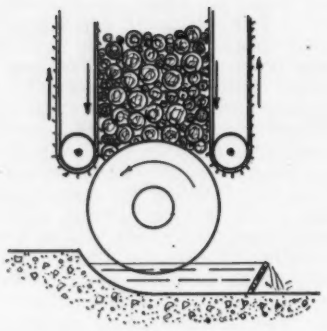

Figure 3—Warren chain grinder

designed but in the later models design was improved so that the number of shims which came out of the grinder pockets was reduced. The operators also had learned the importance of maintaining grinder pits free of shims.

The essential features which we wanted in a grinder were in this design. The next thing to work out was a convenient means of getting the wood to the magazines. Water conveyors were arranged so that the wood could be floated directly to the grinders at just the right height so that a man with a pick pole or pickaroon could lift the end of a stick and slide it out into a sluice, which would guide it down to the grinder pocket magazine. Handling the wood this way is like taking hold of a boat which is floating in the water. Very little effort is required to lift one end out of the water. The water conveyor was made slightly over four feet wide so that the wood could be floated crossways to the conveyor. This saved the grinderman the work required to turn sticks, necessary when the wood came down the conveyor lengthways. Turning one stick is not much work but a grinderman is handling about 2000 sticks in an eight hour day. The Great Northern Grinder is illustrated in *Figure 5*. The method of feeding pulpwood into the grinder is shown in *Figure 6*.

The first Great Northern Grinder installation was in the East Millinocket Mill. Problems and troubles developed quickly. The general design of the grinder was like the one in *Figure 4*. Pulp, instead of going into the grinder pit, stayed in the pockets so there was no room to put in the next charge of wood. Eventually we

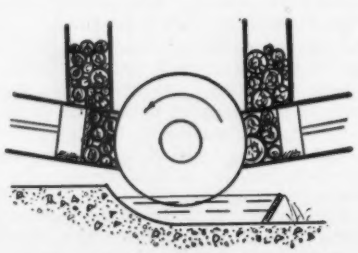

Figure 4—Great Northern grinder

found that this trouble was due to lack of sufficient clearance between the pulpstone and the sides of the grinder casing. The small space provided was too easily plugged by dry pulp and shims. The next grinders were built with wider casings and this trouble was eliminated.

Another trouble was the excessive number of shims which came from the pockets into the grinder pit, causing the usual trouble with local hot spots that overheated and damaged the pulpstones. The cause of the excessive number of shims was traced to deflection in the grinder shaft. The increased power input to the new grinder required higher grinding pressure. The grinder bearings were spaced farther apart to allow for the four foot width stone. The result was a shaft deflection of 3/16″ when full pressure of 80 tons was applied to one pocket, and that much clearance had to be allowed between the pocket fingers and the stone or the stone would grind the fingers. This 3/16″ opening was big enough to let thin slabs of wood or shims drop into the grinder pit instead of being held in the grinder pocket and ground into pulp. Having found the cause of the trouble the answer was easy. Increase size of the grinder shaft. The diameter of the shaft in the next grinder was increased from 10″ to 14″. The deflection was only 1/16″ which caused no trouble.

These two minor changes in design turned what looked to be a failure into a very successful pulp grinder. Today more than 50 percent of the groundwood pulp manufactured in the United States is made by Great Northern Grinders. The Canadian mills however have continued to install the Waterous Hydraulic Magazine grinders or later models of Voith-Warren chain grinders. Recently an installation of Waterous-Great Northern Grinders was made in a Quebec Mill. This grinder combines the short one charge magazine and the top lathe of the Great Northern grinder with horizontal pockets and control valve arrangement of the Waterous hydraulic magazine grinder. Another Canadian mill made an installation of Roberts Grinders. This most recently developed pulp grinder applies an entirely new method of building up grinding pressure of the wood against the pulp stone.

Roberts Grinder. A sectional view of the Roberts or ring grinder is shown in *Figure 7*. This grinder has the same advantage as the chain type grinders in that the load is applied continuously with no interruptions to refill the pocket. The pressure is generated by the friction between the wood and the stone which jambs the wood in the acute angle between the stone and the ring. The inside surface of the ring or cylinder is rough and holds the wood without slipping. The outside ring is allowed to rotate at a speed which will advance the wood just fast enough to absorb the

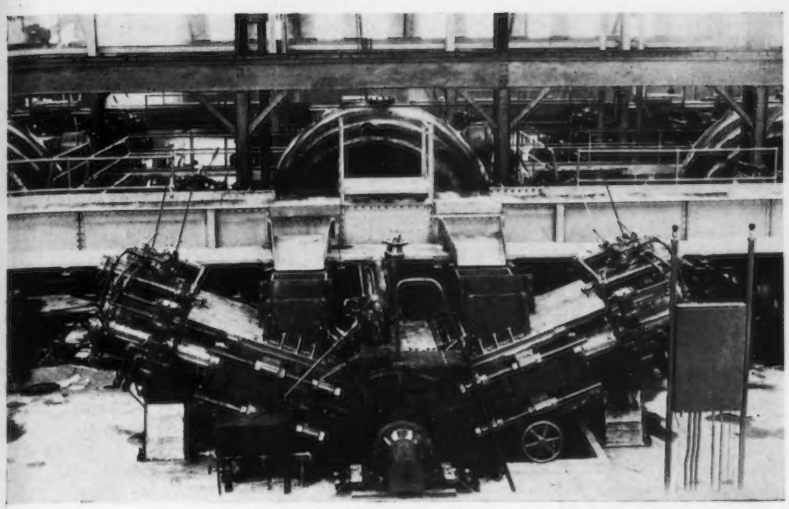

Figure 5—Great Northern Grinder

power for which the ring speed governor is set. The speed is controlled through the heavy gear on the outside of the ring meshing with a worm gear which in turn is connected through smaller higher-speed gearing to the variable speed governor motor. The ring is held in a fixed position by bearing blocks which bear against the two bearing rings, one on each side of the big ring gear. The sharpening lathe is located directly above the stone inside the ring. In this position it is difficult to protect the lathe from pulp, steam and corrosion. Use of stainless steel construction minimizes this trouble. As I have mentioned previously, using the same horsepower-days per ton, the pulp quality is about the same as with other types of grinders. The first Roberts grinder units built had serious operating difficulties which were gradually overcome with minor changes in design. As you can see in *Figure 7* the speed of the large outside ring is controlled by the worm gear which meshes with the large ring gear. The thrust bearings on the worm shaft are subject to heavy loads and in the original models these thrust bearings failed in a short time. A thrust bearing with greater capacity was designed and installed to overcome this weakness.

The Roberts grinder has the advantage of very steady load regulation when grinding spruce and fir wood. Recently a new newsprint mill in the South was equipped with Roberts grinders. There has been considerable difficulty in getting steady load regulation on the grinder drive motors. This difficulty has been traced to the fact that the southern pines which are being ground are much denser wood than the spruce and fir used in the northern installations. The natural spring or cushion of the spruce and fir under pressure prevented sudden changes in load. The pine wood, being so much less compressible, transmitted the load changes so quickly that the governor did not have time to adjust to a steady condition. Changes in governor design have improved the load regulation.

In some installations of the Roberts grinder the wood is floated to the grinder in a water sluice similar to the one used with the Great Northern grinder installations. The wood is fed into the grinder through a door located in the side. This method of feeding necessitates more manipulation of the wood, so that the Roberts grinders require more operating labor than the Great Northern grinders.

There is one field where two foot grinders are still in operation, and will probably continue to be used. This is the field of very high grade groundwood pulp which must be clean and free from discolored fibers. The main reason for this is that pulpwood comes to the mills usually in four foot lengths. The surface is weathered and darkened if it has been cut for some time. By looking at a stick it is impossible to tell if the stick has a discolored rotten heart unless a fresh surface is exposed. A saw cut through the middle of the stick makes it easy to detect and discard defective blocks. This makes the difference between getting clean or dirty pulp, and adds to the cost. It is necessary when the mill is making a very high grade of pulp.

The Pulpstone

We will now proceed with the discussion of the pulpstone itself. A grinder is not of much use unless there is a good pulpstone with it. With the development of large grinding units there had to be a corresponding development of pulpstones. Prior to 1925 practically all pulpstones were made from selected types of sandstone. Certain definite qualities were required to make a good pulpstone. The stones had to be uniform in hardness and have the proper grain or grit size. Natural sandstone is a deposit that was probably the bed of a river where the velocity of the current segregated the sand grains of different sizes before hardening into sandstone.

Even in the days of two foot grinders there were many attempts to make artificial stones. Sand was sifted into the right sizes and mixed with cement, but this was never very successful. It was difficult to get the required strength to stand temperature changes and high pressure. Inventors tried making metal stones with various types of file-like surfaces. These were useless. In the first place there was no way to sharpen the surfaces. In the second place the surface would have rusted and corroded so quickly that, if it could have been sharpened, it probably would not have been successful.

As the four foot grinders were developed, the problem became more acute and actually limited the installation of four foot grinders. There were plenty of sandstones two feet thick which were uniform in structure; but to find stones four feet thick and uniform in structure multiplied the problem a good many times. This is represented on a cost basis by the

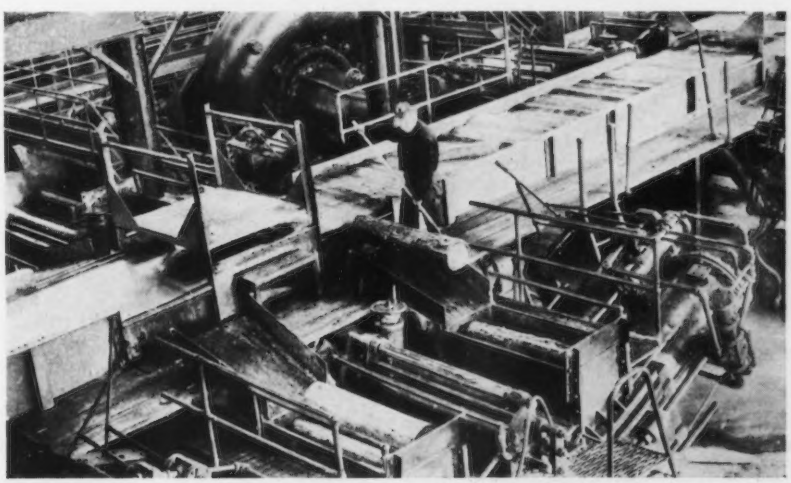

Figure 6—Feeding Pulpwood into Grinder

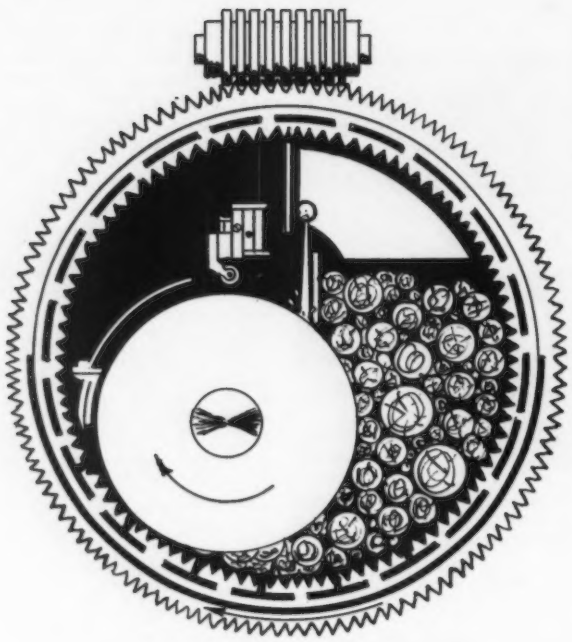

Figure 7—Roberts Type Grinder

experience in our Madison mill after the installation of Warren Chain Grinders. The cost of the two foot stones had been $200 and the cost per ton when the stone was worn out was about ten cents a ton. Four foot stones for the new grinders cost $1200. Many more of the four foot stones were imperfect and they broke more frequently. The first year the new grinders were in operation the stone cost was over $1.00 a ton of pulp. Of course this higher price made the development of a successful artificial stone much more attractive. The Norton Co. attacked the problem and started making experimental stones and was the first company to succeed. The first Norton stones were made with silicon carbide grit and various types of bonding material. As usual the first results were not satisfactory. The Norton Company first tried to duplicate the construction of a natural stone making the stone in one piece with a hole in the center for the shaft to go through. It lasted exactly two hours in a two foot grinder before it broke. The structure did not stand the strains set up by the quick temperature change which occurs on the surface of the stone when starting to grind wood. The Norton Company engineers recognized the problem as one of expansion. Their next stone was made up of thin sections shaped like so many doughnuts which were held together by the flanges on the stone shaft. This change in design made only a slight improvement in the life of the stone. The engineers then realized that the problem was to allow circumferential expansion. Both the Norton Co. and the Carborundum Co. accomplished this by making segmental stones. The segments are made separately and are then assembled on a core. Originally the Norton Co. core was made of cast iron. The segments were held to the core by dovetail keys recessed into the segments and bolted to the core. *Figure 8* is a diagram of one of the Norton Co. stones of a later model. This construction solved the main problem and one of these stones ran ten years in the Millinocket mill. In that period it produced over 60,000 tons of pulp. These stones cost about $5,000 compared with $1,200 for the natural sandstone but they lasted, on an average, three years instead of three months.

Later, reinforced concrete cores were found to be cheaper and satisfactory. They were used in place of the more expensive cast iron cores. In a still later design the segments were cemented to bolts set in the concrete core. The Carborundum Co. used a different system. A groove was cast in the sides of the segments which were then assembled on steel rings so that the segments were keyed down by steel rings rather than held by bolts. Later, this arrangement was changed because when one segment broke it could not easily be replaced. The segments of the present model Carborundum stones are held to the core by the hook bolts which go into holes in the side of the segments and anchor them to the core. The segments are spaced about one quarter of an inch apart to allow for expansion, and the gap is filled with rubber, or other material, which will allow for the expansion of the segments. The segments are thin and porous so that the moisture and heat go through quickly. The segments are not bonded to the concrete core and depend on the bolts to hold them in place.

While both the Norton Co. and the Carborundum Co. solved the problem of complete stone failure minor problems remained. Individual segments sometimes cracked. In the early stones this was more frequent in the Carborundum stones, so that the Norton Co. received the biggest proportion of the pulpstone business for the first ten years. The Carborundum Co. kept experimenting and eventually found a method of moulding and baking the segments so that cracks did not develop often. Today both companies are putting out pulpstones which give very good service.

In connection with the Norton Co. pulpstones there is an interesting story which indicates what you may have to contend with someday when you have responsibility for production. The Norton Co. employed a very careful Swedish workman who, from experimental days, had assembled the pulpstones. He prepared the cement grout used to hold the segments on the bolts. During this period most of the Norton pulpstones gave good service. This particular workman died. Apparently all the technique of assembling the stones had been written into the standard procedure. However, the segments on stones assembled by the Swedish workman's assistant began to fall off the holding bolts within six months of the time they were put in service. The Norton Co. engineers worked on the problem. They thought that the trouble must be due to a change in the quality of the cement, so the cement was analyzed and tested but no measurable difference could be found. They experimented with different cements and methods of assembling for five years. Finally, to make a successful stone again, the design of the holding bolts was changed. It cost the Norton Co. thousands of dollars to settle claims for defective stones. To this day nobody knows the secret of the Swedish workman's success.

We have discussed some of the mechanical failures and successes in pulpstone development. Experiments with different types and sizes of grit and different bonding materials were carried along during the development. Stones could now be made with grit of controlled sizes and with any desired hardness. The percentage of grit to bonding material could be varied.

Burring and Other Grinding Variables

Burring. The first problem which the grinder operator ran into after he had a stone which would hold together, was the sharpening of the artificial stone. He got inferior pulp when he sharpened as he had previously. For several years many mill operators thought that a mill could not be run using all artificial stones, because the desired quality of pulp could not be made. That problem was also solved very satisfactorily so that today very few natural sandstones are used. The solution required a change in the method of sharpening the stones, not in principle but in refining the details.

The natural sandstone wore down so quickly after it was sharpened that if the surface was too rough at first it would naturally smooth out in a few minutes. If a pulpstone face is too sharp the wood fibers are cut instead of being rubbed apart. The pulp produced is short and chunky and, in a thin sheet, will not hold together to make good paper. Good pulp is ground with a moderately dull stone which, however, cannot be too dull or power is wasted. To control the cutting rate the face of the pulpstone is marked with a pattern of shallow grooves. This pattern of grooves is applied to the face of the stone by a burr mounted on a mandrel which is fastened in the lathe head but allows the burr to rotate freely. The lathe head is moved across the face of the stone at the same time that the burr is pressed against the stone face with moderate pressure. Contact between the burr and the stone keep the surface speed of the stone face and the burr face the same so that the teeth on the burr face cut grooves in the stone face.

With sandstones the burr used usually had a broad base tooth with a 45 degree slope on each side. These burrs worked well on standstones but when they were applied on an artificial stone face it tended to crush the face. The solution was to make a burr with a very thin tooth and apply it with light pressure which would cut the grooves without crushing the face. This method of sharpening builds up a strong face pattern which wears down slowly when the stone is grinding. The face should last a week before sharpening again is necessary. When sharpening properly with good equipment the burr teeth will mesh with the grooves in the face of the stone. This will deepen the grooves but will not dislodge the dull grits on the top of the ridges which do the actual grinding. Thus there is no period of poor quality pulp from the freshly sharpened stone.

We found that a large grinder requires a very accurate and solid lathe. If there is any vibration when the burr is pressed against the stone the top of the ridges will be broken off. The lathes on the first two Great Northern grinders were constructed so lightly that there was vibration when sharpening. The stone surface became rough and the next sharpening there was more vibration and the stone became rougher and the burr pattern irregular. The lathe was discarded and a new lathe designed which had much heavier construction and was, at the same time, more sensitive to control so that the sharpener could judge the pressure with which the burr was held against the stone.

The point which I wish to emphasize is that to get good pulp from artificial pulpstones it is important to get uniform speed of burr travel across the stone, to maintain uniform pressure of the burr against the stone, to keep the lathe free of vibration and accurately aligned with the stone shaft, and to be sure that the burr has thin teeth. With these improvements in sharpening, the quality of pulp produced on artificial stones was as good, and eventually better, than the pulp produced on the old two foot grinders.

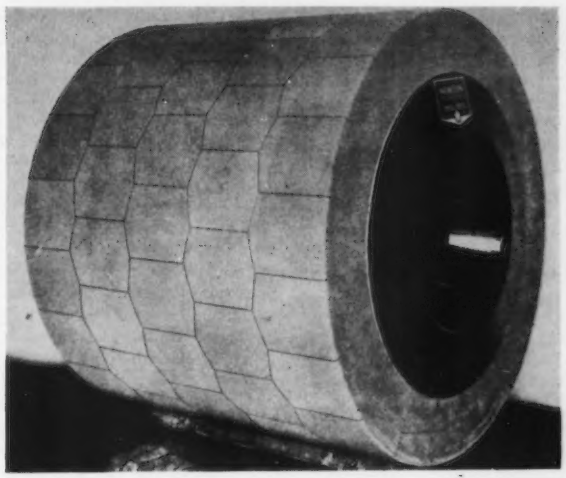

Figure 8—Stone on Which Groundwood is Made.

Grit. Artificial pulpstones are made from two main kinds of grit. One is silicon carbide and the other is aluminum oxide. The Norton Co. and the Carborundum Co. use both kinds. The size of the grit chosen for a particular pulpstone depends on what grade of pulp is to be made. For newsprint grade a medium grit stone classified as 50 or 60 grit is used. For making insulating board stock a very coarse grit classified as 20 or 24 is used. For making groundwood for high grade groundwood printing papers the required grit size would be 80 or 100. The grit sizes are established by the size of the wire mesh through which the grit particles can be sifted.

The burr used gives some control of quality within certain limits, but cannot compensate for the wrong choice of grit size in the pulpstone. In general the finer (more teeth to the inch) burrs produce a finer shorter pulp, but with a given stone there are limits beyond which a burr change is not effective.

Temperature. There are other variables which affect the quality of pulp beside the stone face, grit size and burr size. The most important one is grinding temperature. In European mills it is standard practice to grind at a low temperature, about 130 degrees Fahrenheit, and the pulpstone is submerged in the pulp from four to six inches. This produces a pulp which is strong. At that low temperature many of the natural resins in the wood do not dissolve out as they do at the higher temperature of 170 to 180 degrees Fahrenheit which is the standard North American practice. The resins remaining in the pulp act as a natural sizing agent and reduce the absorbency of paper made from it. The high temperature grinding tends to produce a longer fibered pulp. When this pulp is made into a sheet of paper there are more voids. The sheet bulks up thicker for the same weight. Dissolving out the resins and making a bulky sheet results in a softer, better printing sheet of paper with fast ink absorption.

When four foot grinders were built and high power applied, one of the big problems was to find some way to regulate the shower water to maintain uniform temperature. Temperature changes came too fast for the operator to regulate the shower water with a hand control valve and get good results. Pit temperature in the two foot grinders was at a maximum of 140 degrees Fahrenheit because it was not safe to work near these grinders at a higher temperature. At a higher temperature, pulp splashing out of the pockets, while the operator was putting wood in them, could cause burns. When operating the large units with more power, the operator was protected from getting splashed with pulp but the temperature changes came so quickly that many times the operator would be too slow in adjusting the shower water. If the stone got too hot the wood carbonized and filled up the stone face. This might damage the stone and in any case would require the stone to be resharpened several times to open up the face. Poor pulp production for some time was the result. The operator usually played on the safe side and kept so much water on that the stone was too cold to grind good pulp. This problem was solved by developing an automatic temperature control which regulated the shower water valve. The earlier attempts were not successful although the instrument was good. It was difficult to find a place for the temperature bulb where the temperature changes were measured quickly enough

to correct the water supply before damage was done. In the grinder pit immediately against the stone there is violent agitation and the temperature changes very quickly. The temperature sensitive bulb was tried in this location but coarse slivers of wood which are mixed with the pulp caught on the bulbs and broke them. The temperature bulb was tried in the bottom of the grinder pit but the response was too slow. The pulp next to the stone is pulled along rapidly with the stone and is thrown off against the under side of the front pocket as the stone emerges from the pulp in the grinder pit. By getting the temperature sensitive bulb firmly fastened on the under side of the front pocket near the stone face there was a quick response to stone temperature changes and the bulb was protected from slivers and shims. The man who first put the bulb in this location patented the idea. The court ruled, however, that this was not an original idea and the patent was held invalid. This location of the sensitive bulb made the temperature controllers effective and in a short time all the mills which had four foot grinders added temperature regulators. Good temperature regulation did more than anything else to improve the quality and uniformity of pulp. It also made it possible and safe to run grinders at temperatures up to 180 degrees Fahrenheit, with the added improvement in quality which that temperature gave.

Wood Quality. During intermission one of you men asked "What happens when the wood is crooked?" You all know that the majority of the wood fibers are parallel to the axis of the stick. In removing the fibers by grinding it must be done so that the stone grits rub the full length of the fiber at the same time so that it gets loosened and then separated. If the pulpwood is not parallel to the axis of the stone it is at an angle and the fibers are ground on the ends. The result is that instead of long fibers being separated there are many small pieces of fiber broken off the ends of the fibers. Much power is wasted and the pulp is of poor quality. In the Great Northern grinders uneven grinding of one charge of wood will automatically be corrected before the next charge of wood is put in, because when the pocket is empty both pressure feet are about one inch from the stone and no uneven wood remains to start uneven grinding when the pocket is refilled. A serious problem with the chain grinders is that when the wood starts to grind crooked it is necessary to reverse the chain feed and lift the magazine full of wood off the stone face, and pull the crooked pieces of wood out through a small door in the side of the magazine. This operation may take half an hour to complete and the production of the grinder is lost.

Of course, good wood is one of the most important factors in producing good groundwood pulp. Sound old-growth spruce free of large knots makes the best pulp. Canadian Balsam Fir is almost as good as spruce and is used, mixed with spruce, in all Northeastern mills today. There is not enough spruce available to satisfy the demand for pulp. The two woods are quite different in density but it is not possible at a reasonable cost to keep the two species separate so they are ground together. The spruce, being more dense, will grind slower but, of course, there is more pulp per cord because the weight per cord is higher. The spruce can be ground to the same quality with less power per ton of pulp. The power for the same quality seems to be proportional to the volume of wood rather than to the weight of wood ground. A mill which has a large percentage of good spruce will make a better showing regardless of the type of grinder used than a mill which is grinding a large percentage of fir. Because of the shortage of spruce and fir, some mills are using jackpine in Canada and the southern pines in the southern part of the United States. Southern pines being more dense and more brittle than spruce require grinding on duller stones, and the pulp is inferior in quality. Two newsprint mills are operating in the south today and use all pine wood but much more chemical pulp must be mixed with the groundwood to maintain standard strength paper.

Pulp Testing

In the previous discussion we have referred frequently to the quality of groundwood pulp but have not mentioned how the quality can be determined. The only 100 percent accurate test is to have the pulp made into paper and have the paper run off on the printing press at full speed. Reports from the press room do come back to the paper and pulp mill but there is a delay of several months so some immediate tests must be used to maintain uniform quality.

There is a difference of opinion among different mills as to how the quality should be controlled and how the quality shall be judged quickly enough to be effective when the necessary changes are to be made in grinding conditions. You are familiar with some of the pulp tests which are used. For groundwood, the test most generally used is the *Freeness* test which is the rate at which water will drain out of a certain amount of pulp under standard conditions. There are five or six makes of freeness testers sold and in use. The results of one tester cannot be compared directly with the results of another make of tester because the calibration methods are different.

The freeness test does not exactly parallel the use of pulp on a paper machine. The major difference on a paper machine running a high groundwood furnish is the recirculation of a large percentage of the fine pulp. On a high speed newsprint machine about 40 percent of the pulp which is delivered on the wire from the slice passes through the meshes of the wire with the whitewater. This pulp is not lost because the whitewater is used to dilute fresh pulp coming from the pulp mill. When a freeness test is run on groundwood there is no way to evaluate the effect of recirculation. It has been proven many times that two different pulps can have the same freeness test and yet have a marked difference in freeness as indicated by drainage rate on a paper machine. In spite of occasional errors the freeness test is the best quick test to determine changes in groundwood quality. But do not argue with the papermaker that the freeness test is right and the paper machine wrong. The paper machine and the paper made are the real test of pulp quality.

Another test used by the grinder operator frequently is the *Blue Glass* test. A very thin suspension of pulp and water is placed on a framed sheet of dark blue glass. This is held under a strong light which shows up the individual fibers against the blue background. The desirable long slender fibers are shown up as well as the fine sawdust-like particles and fiber bundles. While an experienced man can judge pulp closely by means of a blue glass test there is no way to tie the results down to a numerical figure which can be checked by another operator. This test is used mostly to check individual stones. In judging pulp from an individual grinder, care must be used and a check test made several times, because if a stick of poor wood is being ground at the time the sample is taken the test would give the same indication as if the stone face were in poor condition. Pulp quality will also be poor if there are several grinders on one line and the pockets on one grinder are permitted to get empty. The governor throws all the load on the remaining grinders on that line with resultant high grinding pressure and poor quality of pulp. Examination and tests of groundwood pulp have to be interpreted on the basis of the conditions under which the pulp was made.

Another way to test pulp is to put a small amount of pulp on a slide and project it onto a screen or look at it under a microscope. This method was sold to the industry a number of years ago as a very excellent way to improve groundwood quality. In practice it did not prove to be much help because the sample of pulp was such a small percentage of the total pulp that one coarse fiber in the sample would completely change the appearance.

On paper machines which are equipped with suction couch rolls and which make the same grade of paper continuously, such as newsprint machines, the vacuum which is main-

tained in the suction box in the couch roll is an indication of pulp freeness and quality. A coarse, weak pulp will be more porous and more air will flow through the sheet causing the vacuum to drop. If a pulp is fine and slow draining the vacuum will increase. In the Great Northern newsprint mills the pulp mills are located close to the papermill and the pulp mill operators judge pulp quality by watching the paper machines. Recording vacuum gauges are on several of the suction couch rolls to indicate and record the changes in vacuum. Changes in paper machine operation such as raising the dandy roll or adding more water in the headbox can change the couch vacuum so that the papermaker and pulpmaker must work together if the couch vacuum is to be used as an indication of pulp quality. In these mills there is a time lag of about three hours before a change in grinding is noticeable on the paper machines. Our normal sharpening schedule is about one stone in eight hours so the time lag is not serious.

Most other mills do run the freeness test and use it as an indication of pulp quality. If the pulp mill is not near the paper mill, freeness tests supplemented by strength tests on hand sheets and fiber classification tests will give the information required to maintain the desired quality.

There is still a lot to be said about making groundwood. I hope you do not think the process is so simple that it is not interesting.

Cooking Acid Preparation in the Sulfite Process

Marcel J. Barsalou

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1. General

The liquor used to obtain pulp from wood by the sulfite process consists of a solution of a metallic bisulfite with a varying amount of free sulfurous acid.

Until recently, the metallic base calcium was almost exclusively used because of its low cost, when used as limestone. Recently, however, because of better methods of recovery and other advantages, magnesium, sodium and the ammonium radical have begun to find a use in the process. The major part of sulfite pulp is, however, still being obtained by the use of liquors containing calcium as a base.

The acid making process consists essentially in burning sulfur or roasting pyrites to obtain sulfur dioxide; cooling the gas as quickly as possible to prevent sulfur trioxide formation by oxidation of the sulfur dioxide and absorbing the sulfur dioxide in water in presence of a base. This absorption is usually carried out in towers and limestone is used to supply the base.

Figure 1 illustrates a fairly typical acid plant. It consists of:

(1) A sulfur burner to burn sulfur to sulfur dioxide.
(2) Combustion chamber to permit complete combustion.
(3) Coolers for rapid cooling of the gas produced.
(4) A fan to create a suction on the burner and a pressure on the gas going to the absorption towers.
(5) Absorption towers filled with limestone through which runs water and to the bottom of which gas is delivered under slight pressure in order to work its way up through the towers.
(6) A settling tank for the acid.
(7) Pumps to raise water to the top of the towers, transfer the acid from tower to tower, etc.

2. Production of Sulfur Dioxide Gas

Sulfur dioxide for acid manufacturing in the sulfite pulp industry is obtained:

(1) By burning sulfur
(2) By burning pyrites
(3) From chemical manufacturers, as liquid sulfur dioxide, in tank cars.

In plants where sulfur is not recovered from the blow liquor and blow gases, the sulfur consumption varies from 190 to 300 pounds of sulfur per ton of unbleached pulp obtained, depending on the type and quality of pulp desired.

A sulfur consumption of 240 pounds per ton of unbleached pulp can be accepted as representative for the manufacture of easy-bleaching sulfite while newsprint sulfite is usually cooked with 200 pounds of sulfur per ton.

2A. Production of Sulfur Dioxide Gas by Burning Sulfur

1) *Sulfur* is a brittle, pale to yellow element which is solid at room temperature. It is insoluble in water but dissolves in carbon disulfide. There are both rhombic and monoclinic crystalline formations, melting at 112.8 degrees Centigrade (235 degrees Fahrenheit) and 119.2 degrees Centigrade (246 degrees Fahrenheit) respectively to an amber colored mobile liquid which upon heating becomes thick. At about 200 degrees Centigrade (392 degrees Fahrenheit) it is so thick that it will not flow and has assumed a dark color. At 350 degrees Centigrade (662 degrees Fahrenheit) the sulfur again becomes fluid and retains its dark color. (See *Figure 2.* Viscosity of Liquid Sulfur).

Because it is most mobile at 260-300 degrees Fahrenheit, sulfur is maintained at this temperature where it is fed in liquid form to sulfur burners.

Sulfur ignites at 248 degrees Centigrade (478 degrees Fahrenheit) and boils at 444.6 degrees Centigrade (832 degrees Fahrenheit).

Practically all the sulfur used on this continent is obtained by the Frasch process from the States of Louisiana and Texas. This sulfur is practically chemically pure, averaging from 99.5 to 99.9 percent sulfur.

All inland mills receive sulfur by freight either in box cars or gondola cars, in which it can be transported because it is not affected by rain and is sufficiently heavy not to be blown about by the wind.

The ideal method of handling surfur consists in having a trestle running over the storage bins so that the cars can be run over the bins and dumped into them. Gondola cars can be unloaded with cranes.

Storage bins for sulfur can be either open or covered. No appreciable sulfur loss is experienced with open bins. One advantage of covered bins, however, is that it prevents sulfur from

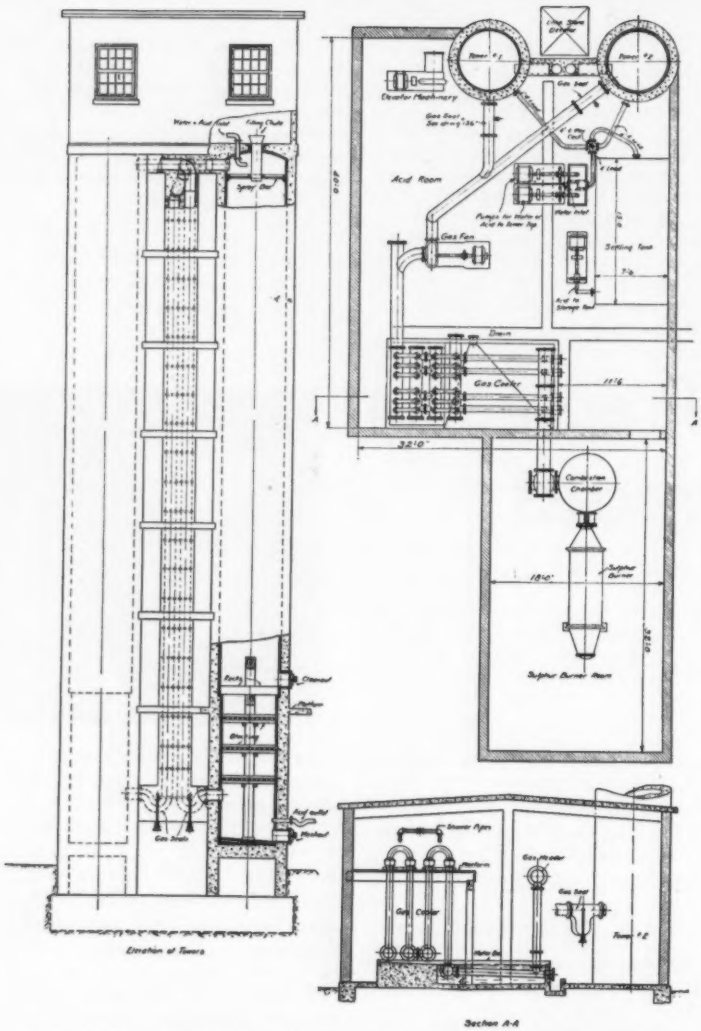

Figure 1—Diagram showing construction and operation of Jenssen tower system.
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blowing on transformers, structural steel, etc., which eventually are corroded by the small percentage of sulfuric acid (0.05 percent) which is always present in sulfur.

(2) *Chemistry and Calculations of the Sulfur Burning Process*—Editor's Note: The following theoretical calculations have been taken from Mr. A. N. Lunberg's book, "Acid Making in the Sulphite Industry" *(1)* with minor modifications and rearrangements by the author.

When burning sulfur in air, one volume of oxygen combines with sulfur to yield one volume of sulfur dioxide:

$$S + O_2 \rightarrow SO_2$$

Moisture free air has the following average analysis:

	Percent by Volume	Molecular Weight	Pounds in One Molal Volume	Percent by Weight
Oxygen	20.95	32.00	6.70	23.1
Nitrogen	78.08	28.02	21.88	75.6
Carbon Dioxide	0.03	44.00	0.01	.0
Argon, etc.	0.94	40.00	0.38	1.3
	100.00		28.97	100.0

For simplification, air in the following calculations is considered to consist of:

21% Oxygen and 79% Nitrogen therefore:

	Percent by Volume	Molecular Weight	Pounds in One Molal Volume	Percent by Weight
Oxygen	21	32	6.72	23.3
Nitrogen	79	28	22.12	76.7
	100		28.84	100.0

Thus when one volume of oxygen produces one volume of sulfur dioxide, it carries:

$1 \times 79/21 = 3.76$ volumes nitrogen

The theoretical possible gas, therefore, will consist of:

1.00 volume SO_2
3.76 volumes N_2

4.76 volumes of gas

and one volume of SO_2 is
$1/4.76 \times 100 = 21\%$ by volume.

To produce the theoretical gas strength given, it would be absolutely necessary to have perfect control of the sulfur and air supplied to the burner to prevent sulfur trioxide formation or sublimation of the sulfur, as will be explained further.

In practice, such perfect proportioning and the required mixing are next to impossible to obtain and if they can be obtained are not worth the difficulties which can be encountered, if the system is thrown off balance.

With the average equipment found in mills, however, it is usually possible to obtain a burner gas containing 17 percent sulfur dioxide and having the following compositions:

17% SO_2
4% O_2
79% N_2

100% gas

Note—Unless otherwise stated the following calculations are all at 760 mm Hg and 32 degrees Fahrenheit and are based on 100 pounds of sulfur.

Sulfur Burning With Dry Air and No SO_2 Formation

Burner Gas		Molecular Weight	Pounds in One Molal Volume	Percent by Weight
17.0%	SO_2	64	10.88	31.7%
4.0%	O_2	32	1.28	3.7%
79.0%	N_2	28	22.12	64.6%
100.0%	gas		34.28	100.0%

It should be noted that the total weight of components in one molal volume is the molecular weight of the mixture *(See Figure 3)*.

Thus:
SO_2 by weight = 31.7%
Total weight burner gas = $200/0.317 = 631$ lbs.
Total volume gas $= \frac{200 \times 359}{64 \times .17} = 6600$ cu. ft.
1 cu. ft. burner gas = 0.0956 lbs.
1 lb. burner gas = 10.47 cu. ft.
(See Figures 4 and 5).

The influence of moist air on the burner gas composition is given below for three representative days.

32° F. air saturated = 0.004 lbs. water vapor per lb. dry air = 0.64% vapor per volume.

62° F. air saturated = 0.012 lbs. water vapor per lb. dry air = 1.87% vapor per volume.

74° F. air saturated = 0.018 lbs. water vapor per lb. dry air = 2.82% vapor per volume. *(See Figure 8)*

Composition of Air

H_2O	0.6%	1.9%	2.8%
O_2	20.9%	20.6%	20.4%
N_2	78.5%	77.5%	76.8%
	100.0%	100.0%	100.0%

Burner Gas Composition

H_2O	0.6%	1.9%	2.8%
O_2	4.0%	3.9%	3.9%
N_2	78.5%	77.5%	76.8%
SO_2	16.9%	16.7%	16.5%
	100.0%	100.0%	100.0%

Sulfur Burning—With 2.8 per cent Water Vapor —No SO_2 Formation

Burner Gas	Molecular Weight	Pounds In One Molal Volume	Percent by Weight
16.5% SO_2	64	10.56	31.2
3.9% O_2	32	1.25	3.7
76.8% N_2	28	21.50	63.6
2.8% H_2O	18	0.50	1.5
100.0% gas		33.81	100.0

Thus:

SO_2 by weight = 31.2%

Total weight burner gas 200/0.312 = 641 lbs.

Total volume of burner gas = $\frac{200 \times 359}{64 \times .165}$

= 6800 cu. ft.

1 cu. ft. burner gas = 0.0944 lbs.

1 lb. burner gas = 10.59 cu. ft.

The amount of sulfur trioxide formed in the correct operation of sulfur burner is sufficiently small to be disregarded in practically all calculations.

(3) *Thermochemistry of the Sulfur Burning Process.* Sulfur melts at 235 degrees Fahrenheit to a mobile liquid, but upon further heating becomes less and less mobile until at 392 degrees Fahrenheit it is so thick that it will not flow.

For this reason melted sulfur is usually kept at 250 degrees Fahrenheit to 300 degrees Fahrenheit.

Melting Calculations:

Data:

Specific heat of solid sulfur = 0.1728

Specific heat of melted sulfur = 0.235

Latent heat of sulfur melting = 16.86 B.T.U.

100 × (235—32) × 0.1728 = 3508 B.T.U.

100 × 16.86 = 1686 B.T.U.

100 × (250—235) × 0.235 = 353 B.T.U.

Heat in 100 lbs. melted sulphur = 5547 B.T.U.

Combustion Calculations:

Notes:

Atmospheric pressure 760 mm Hg (A)

Radiation not taken into consideration

Air (dry) entering 72° F.

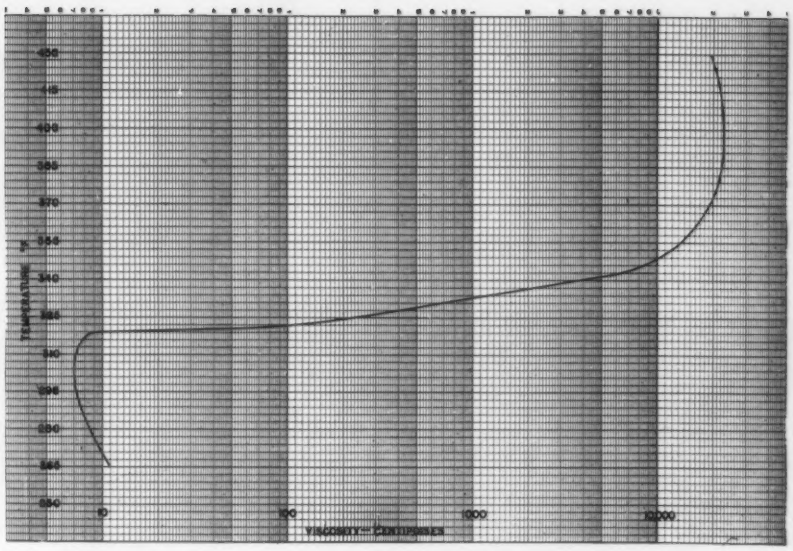


Figure 2—Viscosity of sulfur.

Final gas: 17% SO_2 — 4% O_2 — 79% N_2 (Dry)

Total volume of air entering = 6588 cu. ft. S.T.P.

Total weight air entering = 533 lbs.

Heat of combustion of sulfur = 3980 B.T.U./lb.

Therefore:

O_2 = 21% by volume = 1383 cu. ft. ÷ 359 = 3.85 mols.

N_2 = 79% by volume = $\frac{5205 \text{ cu. ft.}}{6588 \text{ cu. ft.}}$ ÷ $\frac{14.50 \text{ mols.}}{18.35 \text{ mols.}}$ = 359

And using *Figure 6*

Heat in air entering =

18.35 × (72 — 32) × 6.95 = 5101 B.T.U.

Or

O_2 = 23.1% by weight = 123.1 lbs. ÷ 32 = 3.85 mols.

N_2 = 76.9% by weight = $\frac{409.9 \text{ lbs.}}{533.0 \text{ lbs.}}$ ÷ $\frac{14.50 \text{ mols.}}{18.35 \text{ mols.}}$ = 28.18

And using *Figure 7*

Heat in oxygen =

123.1 × (72—32) × 0.216 = 1064 B.T.U.

Heat in nitrogen =

409.9 × (72—32) × 0.245 = 4018 B.T.U.

Heat in burner gas is, therefore:

Heat in melted sulfur entering =	5547 B.T.U.
Heat in air entering =	5101 B.T.U.
Heat in combustion of sulfur =	398,000 B.T.U.
Total heat in burner gas	408,648 B.T.U.

If raw unmelted sulfur is fed into the burner, instead of melted sulfur as above, the heat in the burner gas is as follows, if we assume:

Temperature of solid sulfur =	72° F.
Specific heat of solid sulfur =	0.1728
Heat in raw sulfur =	
100 × (72 — 32) × 0.1728 =	691 B.T.U.
Heating in air entering =	5101 B.T.U.
Heat of combustion of sulfur =	398,000 B.T.U.
Total heat in burner gas =	403,792 B.T.U.

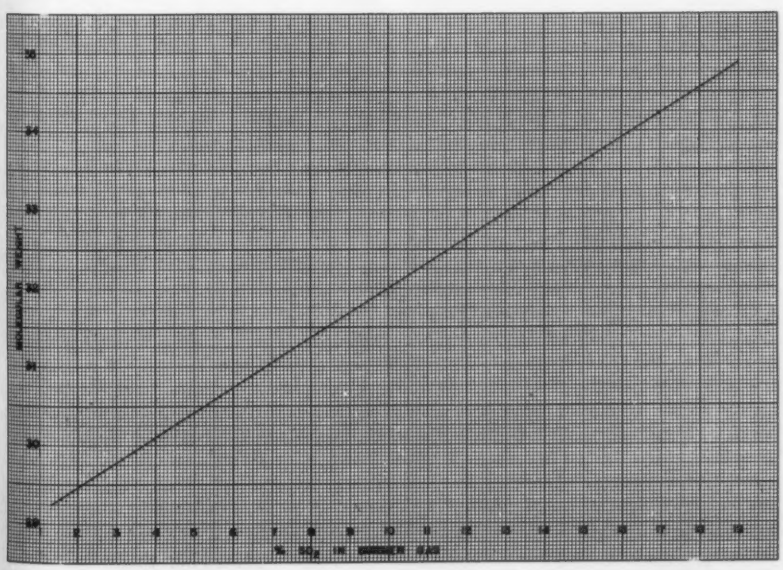


Figure 3—Molecular weight of burner gas at various SO_2 Concentrations.

If we assume that the air entering the burner is 65 percent saturated and at 72 degrees Fahrenheit, we have the following heat in the burner gas:

According to *Figure 8*, saturated air at 72 degrees Fahrenheit contains 0.01692 pounds water vapor per pound of dry air.

And at 65 percent saturation it will contain $0.01692 \times 65/100 = 0.011$ pounds of vapor per pound of dry air.

As seen above, the weight of air required to burn 100 pounds of sulfur at 17 percent SO_2 is 533 pounds.

Therefore, the air will contain $(533 \times 0.011) = 5.80$ lbs. of water vapor, and—

O_2	= 123.1 lbs.	÷ 32.00 =	3.85 mols.	× 359 =	1383 cu. ft. S.T.P.
N_2	= 409.9 lbs.	÷ 28.18 =	14.50 mols.	× 359 =	5205 cu. ft. S.T.P.
H_2O	= 5.8 lbs.	÷ 18.02 =	0.32 mols.	× 359 =	115 cu. ft. S.T.P.
	538.8 lbs.		18.67 mols.		6703 cu. ft. S.T.P.

The heat in the air entering will be:

O_2 and N_2 = 18.35 × (72-32) × 6.95	= 5101 B.T.U.
H_2O = 0.32 × (72-32) × 8.35	= 107 B.T.U.
	5208 B.T.U.

And the total heat in the burner gas will be:

Heat in melted sulfur	= 5547 B.T.U.
Heat in air entering (65% saturated 72° F.)	= 5208 B.T.U.
Heat of combustion of sulfur	= 398,000 B.T.U.
Total heat in burner gas	= 408,755 B.T.U.

Radiation losses of the burner gas appears to vary between ten and twenty percent, depending on the type of system used. For most calculations an arbitrary 10 percent radiation loss can be assumed.

Total heat in burner gas	= 408,755 B.T.U.
Radiation 10 percent	= 40,875 B.T.U.
Total available heat in burner gas	= 367,880 B.T.U.

It is of importance to know the temperature which will be reached by the gases during the combustion of sulfur so that the proper materials will be used for the construction of burner, combustion chamber, pipes, and first part of the coolers.

Lundberg *(1)* gives the following method for arriving at the burner gas temperature.

He first gives the following heat capacities for the various combustion gases, without mentioning his source, but stating that while these figures are not as accurate as others found in the literature they are easier to use.

Heat capacities in Kilogram Calories per Kilogram per degree Centigrade. (T = °C)

SO_2 gas = $0.145T + 0.000030T^2$
N_2 gas = $0.245T + 0.000014T^2$
O_2 gas = $0.216T + 0.000014T^2$
H_2O gas = $0.453T + 0.000067T^2$

Note: To convert Kg. Calories per Kg. to B.T.U. per pound multiply with 1.8. Assuming the conditions outlined in calculation (A) we have:

$SO_2 = 200.0 \times (0.145T + 0.000030T^2)$
$O_2 = 23.1 \times (0.216T + 0.000014T^2)$
$N_2 = 409.9 \times (0.245T + 0.000014T^2)$

633.0

and:

$SO_2 = 0.00600T^2 + 29.000T$
$O_2 = 0.00032T^2 + 4.990T$
$N_2 = 0.00574T^2 + 100.426T$

$0.01206T^2 + 134.416T$

and:

$0.01206T^2 + 134.416\ T = 408648 \div 1.8$
(Convert answer of example A into Kg. Calories per Kg.)

Using formula:

$$AT^2 + BT - C = 0$$

We have:

$$T = \frac{-B \pm \sqrt{B^2 - 4AC}}{2A}$$

Or:

$$T = \frac{-134.416 \pm \sqrt{134.416^2 + 4(0.01206 \times 227027)}}{2 \times 0.01206}$$

$T = 1490°$ C or $2714°$ F.

If, on the other hand, we use the conditions outlined in calculations (B), (65 percent saturated air at 72° F.) we will have the following temperature:

$SO_2 = 200 \times (0.145\ T + 0.000030T^2)$
$O_2 = 23.1 \times (0.216\ T + 0.000014T^2)$
$N_2 = 409.9 \times (0.245\ T + 0.000014T^2)$
$H_2O = 5.8 \times (0.453\ T + 0.000067T^2)$

and:

$SO_2 = 0.00600T^2 + 29.00\ T$
$O_2 = 0.00032T^2 + 4.900\ T$
$N_2 = 0.00574T^2 + 100.426\ T$
$H_2O = 0.00039T^2 + 2.627\ T$

$0.01245T^2 + 137.053\ T$
$0.01245T^2 + 137.053\ T = 367880 \div 1.8$
$T = 1330°$ C. or $2426°$ F.

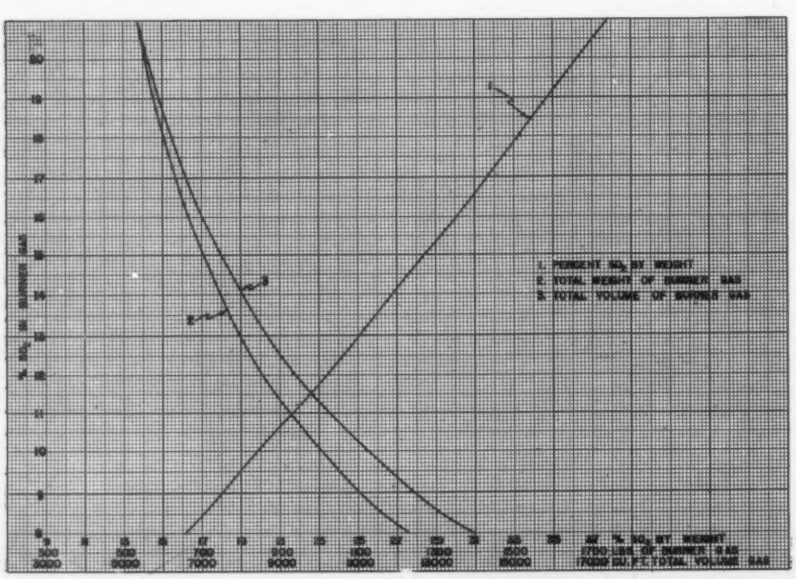
The above calculations can be checked against the values given in Perry *(Figure 6)* as follows:

SO_2	3.12 mols.	× 11.82 =	36.88
O_2	.73 mols.	× 7.52 =	5.49
N_2	14.50 mols.	× 7.52 =	109.04
H_2O	0.32 mols.	× 9.75 =	3.12
			154.53 × (2473-32) = 370.254 B.T.U.

It should be kept in mind that calculations for burner temperature are at best only approximative since specific heats of gases at high temperatures are not very reliable and radiation losses will vary with the type of burner and the kind of construction materials used.

Figure 9 gives the theoretical temperature rise for the combustion of sulfur in air at various gas concentrations. This curve is based on calculations made with specific heats obtained by Eastman of the U. S. Bureau of Mines. Also shown in the figure are small triangles indicating the temperatures obtained at 17 to 18 percent sulfur dioxide in a spray type burner at the Edmundston Plant of Fraser's. These temperatures are 100 to 200 degrees Fahrenheit below the theoretical temperatures, which would indicate a radiation loss of about five percent, if we accept the theoretical temperature as correct.

(4) *Sulfur Melters* — Spray burners must be fed with melted sulfur. Rotary burners can be fed either solid or melted sulfur, but the trend is towards liquid sulfur feeding since it is



From *Acid Making in the Sulphite Pulp Industry*, Lundberg. Courtesy G. D. Jenssen Co., Watertown, N. Y.
Figure 4—Weight and volume of burner gas at S.T.P. (Based on 100 lbs. Sulfur Dry Gas.)

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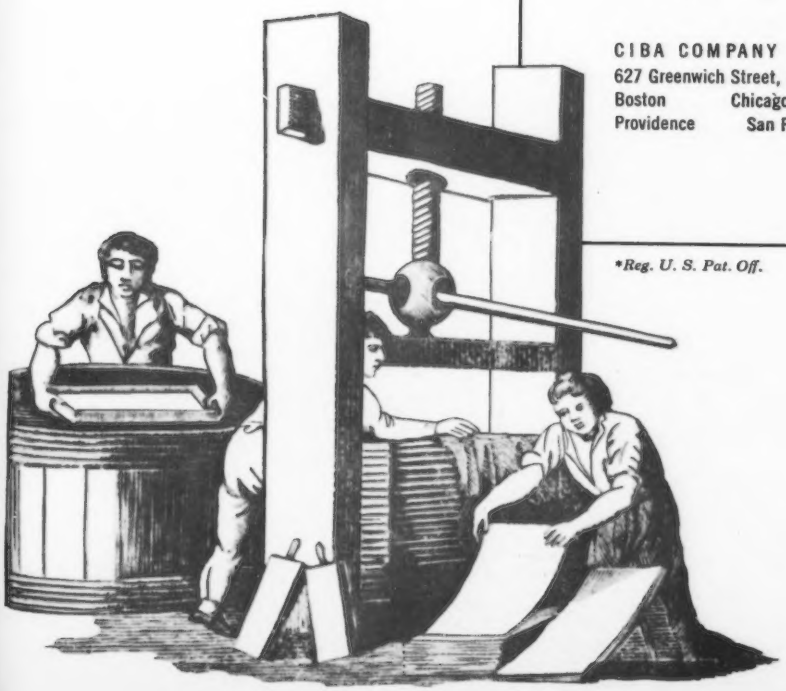

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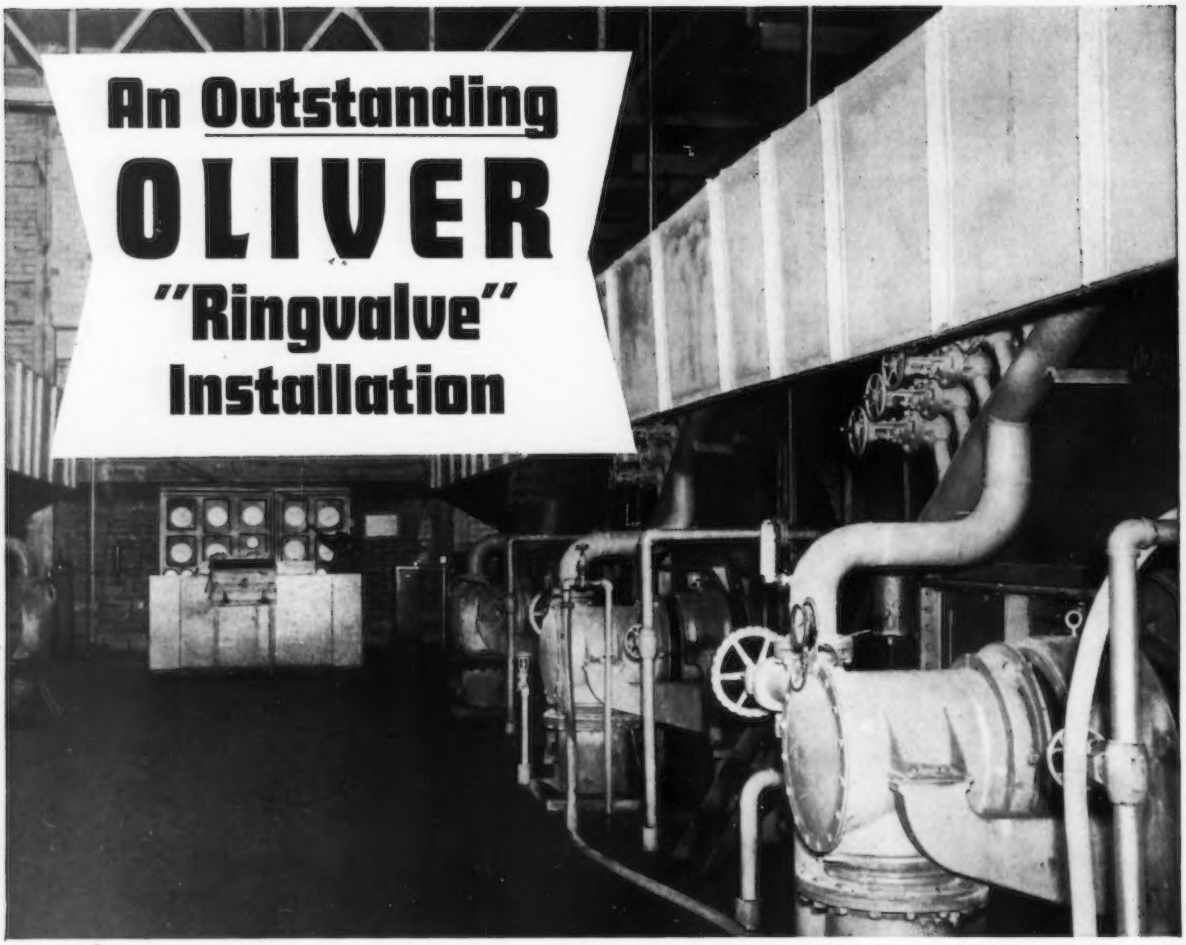

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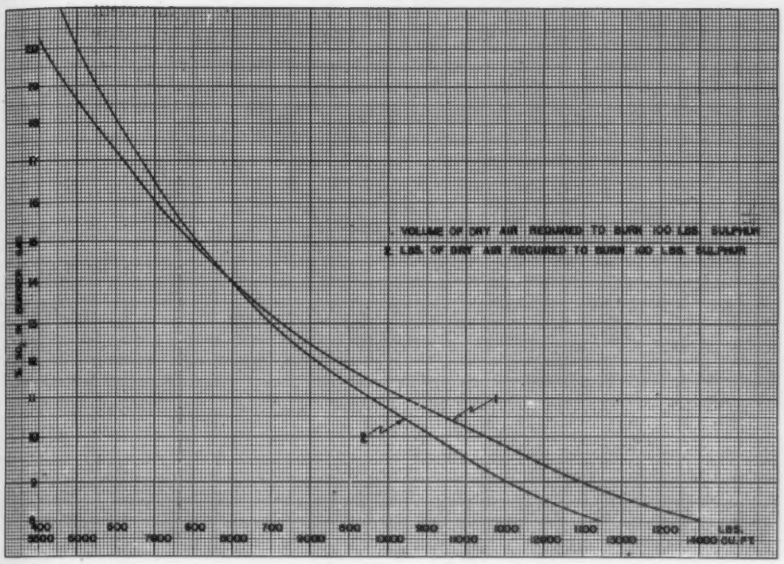


Figure 5—Weight and volume of dry air required to burn 100 lbs. Sulfur.

easier to maintain constant sulfur level in the burner by this method of feeding and more even gas concentration is obtained. This is particularly true if a constant level meter is used to control the sulfur level in the burner.

An added advantage of feeding melted sulfur to burners is the fact that any moisture present in the sulfur is evaporated in the melter, which is usually kept at 265-300 degrees Fahrenheit, and considerably less sulfur trioxide is formed during the combustion of the sulfur.

It should be kept in mind in handling sulfur in acid plants that sulfur dust is almost as explosive as coal dust and for this reason bucket elevators, etc., used for handling sulfur should be so built as to prevent dust spreading. If any dust does accumulate on walls and ceilings, it should be cleaned off.

Sulfur can be melted either in (1) cement pits located below floor level; (2) cast iron tanks located above the burners, (3) Tegul sulfur melters or, (4) tubular sulfur melters.

Pit Melters — These are made of cement and located below floor level. In them are placed cast iron steam coils running the full length of the pit and the sulfur is dumped into the pit at the end opposite to that at which the sulfur pumps are located. The pump intakes are located inside mesh wire baskets (0.036" perforations) which prevent the admission to the pumps of small pieces of wood, gravel and other foreign materials.

It is best to equip the steam coils with loose sleeves where the solid sulfur is dumped, since the sulfuric acid present in the sulfur corrodes the coils at this place, and the whole coil must then be changed.

Pits must be cleaned about once a year to remove the accumulation of dirt from the bottom. This material gets very hard on cooling and it is usually necessary to use a drill to break it up.

A melting tank 32 feet 4 inches long, 8 feet 3 inches wide and 42 inches deep, having a capacity of 74,000 pounds of melted sulfur, will melt over 45 tons of sulfur per day, if equipped with six banks of steam coils made of one inch pipe and heated with steam at 80 pounds pressure.

Tank Melters Over Burner — These are usually square or rectangular, homemade cast iron tanks equipped with steam coils and mounted on a frame over the burner. The heat given off by the burner is supposed to help melt the sulfur, thus reducing the amount of steam required for the melting operation.

Because these tanks are usually built at the mill from odds and ends and fitted into already existing systems, no reliable figures on their efficiency are available.

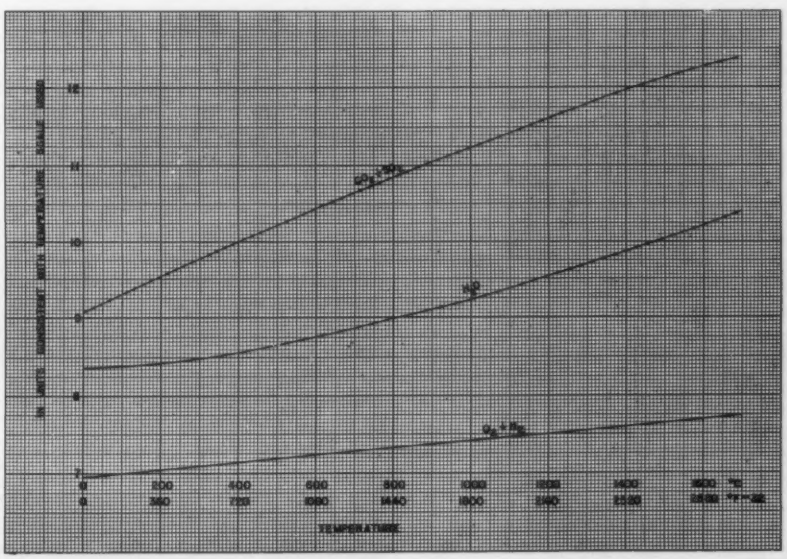
Tegul Melter—The information concerning the description of the Tegul Melter is taken from *Pulp and Paper Manufacture,* Volume I (9).

"This melter *(Figure 10)* consists of a rectangular tank or shell provided with steam coils at its sides and in its interior. The lower part of the shell is provided with inclined, steam-jacketed, V shaped troughs, the crests of which are about 10 in. apart. Slightly above these troughs and directly over their centers are placed additional steam coils.

"Sulphur is charged into a hopper over the melter, and its weight presses it against the steam coils and heated troughs. The steam coils directly over the troughs prevent bridging and ensure a constant feed of sulphur to the heating surfaces. The melted sulphur flows in the inclined V-shaped troughs and is discharged through a series of small openings in the side of the shell into the steam-jacketed trough on the outside of the tank.

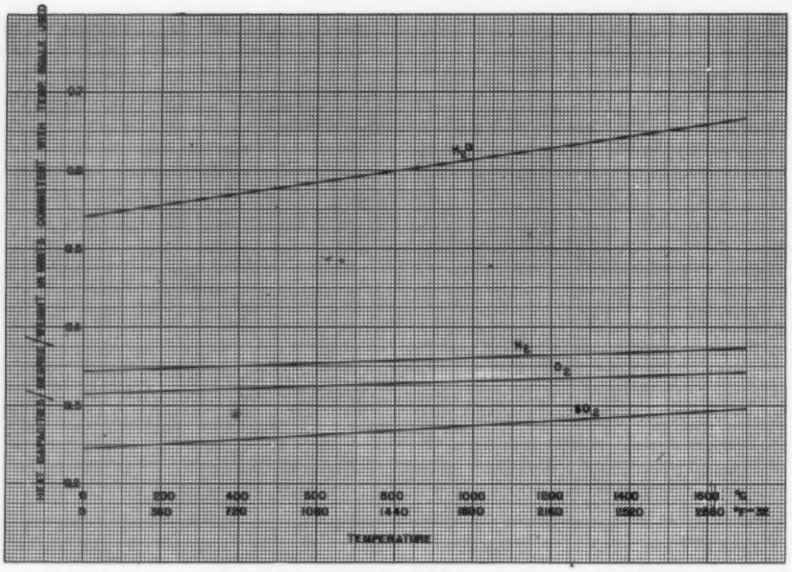
"The rated capacity of this melter at 100 lb. gage steam pressure is approximately 150,000 lb. per day, for a melter having a heating surface of 154 square feet or 1,050 lb. of sulphur per day per square foot of heating surface."

Tubular Melter — The information



From *Chemical Engineer's Handbook, 2nd Ed.,* Courtesy McGraw Hill Book Co., Inc., New York.

Figure 6—Heat capacities of gases.



From *Acid Making in the Sulphite Pulp Industry,* Lundberg, Courtesy G. D. Jenssen Co.

Figure 7—Heat capacities of gases.

concerning the description of the CIL tubular melter is taken from *Pulp and Paper Manufacture,* Volume I (9).

"This melter *(Figure 11)* is trouble-free and has low maintenance costs. It consists of a vertical cylinder set over a concave bottom section. Both cylinder A and bottom pan E are steam-jacketed, as is the delivery pipe F, steam entering at B and G and emerging partly or wholly condensed at C and H. The lugs J support the cylinder. In operation the sulphur is fed at D, and molten sulphur flows down the inner side of the melter to the collecting pan, from whence it flows through the outlet pipe to the pits. Debris which finds its way into the sulphur during the shipment and storage is for the most part carried out by the liquid and is screened out.

"The melter operates on any pressure from 50 to 100 p.s.i. with the optimum at 75 p.s.i. The melting rate can be varied by adjusting the steam pressure or the sulphur feed. The melter can be brought up to production in 10 to 15 min. or closed down in approximately the same time. The capacity per melter is normally 50,000 lb. per day, but under optimum conditions, it will melt up to 70,000 per 24 hr."

The tubular melter will melt up to 10.7 lb. of sulphur per pound of steam. The tubular melter has an efficiency about twice that of melting pits and has about three times its capacity.

(5) *Sulfur Burners* — In the early days of the industry, the flat or retort burner and the Vesuvius burner were used for producing sulfur dioxide. These burners, however, gave gas of irregular strength and usually low concentration, and for these reasons are almost never used today.

We will limit our description of sulfur burners to the two types which are almost exclusively used today, namely, the rotary burner and the spray type burner.

Rotary Sulfur Burner — The quoted material concerning the description of the rotary sulfur burner is taken from *Pulp and Paper Manufacture* Volume I (9).

"This consists (see *Figures 12 and 13*) of a cast iron or steel cylinder A, to which are riveted the conical ends B. The burner rests on rollers K, which are revolved by means of gears, giving the horizontal cylinders a slow rotating motion at about 1½ r.p.m. Burners are built in different sizes, depending upon the requirements."

The burner may or may not be lined. Lining is resorted to for heat conservation and experience has indicated that linings are difficult to maintain in this type of burner.

"The front cone of the burner has a damper F to regulate the admission of air; it is also equipped to receive the sulphur, either in solid form, by means of a worm from a hopper placed immediately in front of the burner, or in melted form, through a pipe C extending through the axis of the burner."

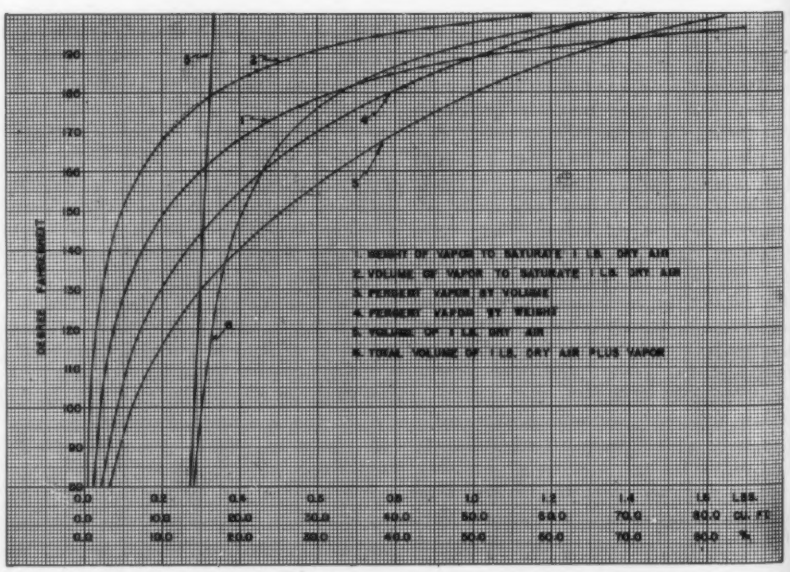
When the burner revolves, the molten sulfur adheres to the side of the burner and is carried up the side where some drops back while the rest is carried around the complete revolution of the cylinder. Thus, the exposed surface of the sulfur mass is increased and gives efficient combustion.

"The rear cone is connected to a short pipe leading to the combusion chamber E. An auxiliary damper H between the rotary burner and the combustion chamber enables the operator to admit and regulate the secondary air necessary for complete combustion."

In starting up a rotary burner fed with solid sulfur, sulfur is first shoveled into the burner. Wood and rags soaked in coal oil are then thrown into the burner and ignited. As the sulfur starts to burn, the drafts are gradually opened in such a way as to maintain a gas relatively high in sulfur dioxide.

When the sulfur in the burner is sufficiently liquid, the burner is rotated and the drafts adjusted to take care of the additional combustion surface.

About five hours are required to



From *Acid Making in the Sulphite Pulp Industry,* Lundberg. Courtesy, G. D. Jenssen Co.

Figure 8—Properties of air mixed with Saturated Water Vapor.

bring a rotary burner fed on solid sulfur up to full capacity and gas strength.

When sulfur is fed in the liquid state to a rotary burner, the sulfur in the tank is first melted with steam and the pipe leading from the tank to the burner thawed out with a blow torch, if the pipe is not steam-pocketed. The operation is then similar to that described above, except that the time required is shorter since it is not necessary to supply heat to melt the sulfur in the burner.

The shutting down of a rotary burner is also a fairly long operation. In practice, to keep a uniform gas strength, rotary burners are kept at constant level, normally about one or two inches from the edge of the small end of the cones. A 5 feet by 15 feet rotary burner will hold 6,000 pounds of sulfur when so filled, so that even after the addition of sulfur has been stopped, the sulfur will require up to six hours to be completely consumed.

During this "burn-down" period, the drafts must be continuously adjusted to maintain the proper gas strength and prevent sublimation or sulfur trioxide formation.

While in full operation, the capacity of a rotary burner can be varied by increasing the fan speed, opening the drafts, opening the sulfur feed pipe wider or speeding up the feed worm (by changing gears) when solid sulfur is fed. Capacity may be reduced by reversing these steps.

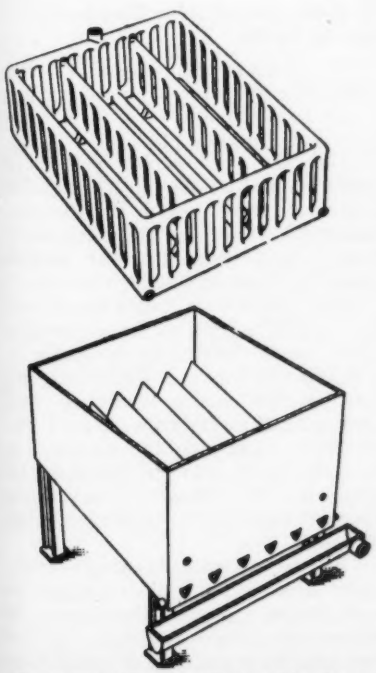


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Figure 10—Tegul sulphur melter.

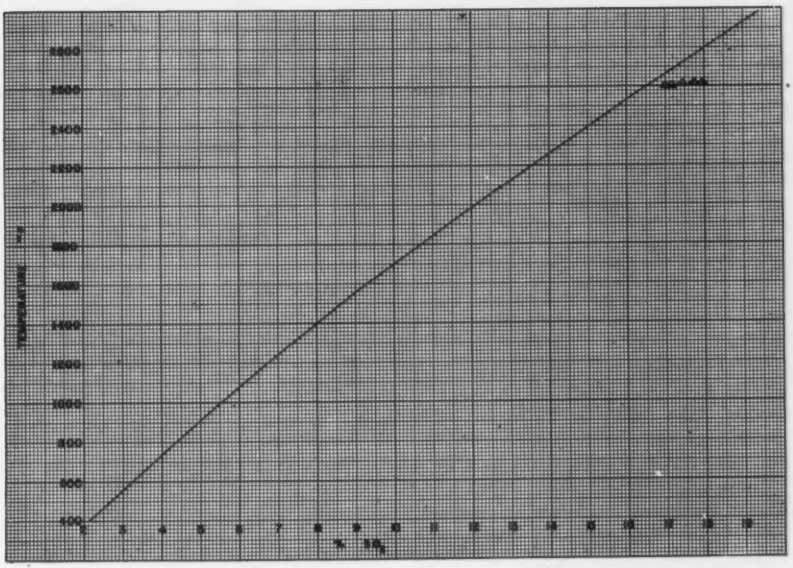

Figure 9—Theoretical temperature rise: S + Air = SO_2

Good burner operation requires the highest possible sulfur dioxide concentration in the gas, consistent with the equipment used. The higher the sulfur dioxide concentration in the gas, the lesser the chance of sulfur trioxide formation, since the oxygen concentration decreases as the sulfur dioxide concentration increases.

On the other hand, care must be taken to prevent sulfur sublimation. If too little air is available, some sublimed, unoxidized sulfur will be carried by the gas into the coolers where the sulfur will condense and quickly plug them up. If, on the other hand, too much air is admitted to the front of the burner and too little at the back damper, combustion will be complete in the burner instead of the combustion chamber and the burner temperature will increase. Since sulfur boils at about 445 degrees Centigrade some unoxidized sulfur will be carried by the gas and the effect will be the same as mentioned above.

When satisfactory combustion is being obtained a blue fire tipped with white is noticeable in the burner. A reddish brown cloud indicates sublimation.

Deviations in the temperature of the pyrometer located in the combustion chamber, flame color, and Orsat analysis of the gas (or automatic sulfur dioxide analyzers) indicate to the acid maker the state of operation of the burner.

As mentioned before, the sulfur consumption per ton of unbleached pulp can vary from 190 to 300 pounds, depending on the quality and grade of pulp required. For this reason, the burner capacity required for a given mill should not be based only on the mill capacity but also on the sulfur consumption per ton of unbleached pulp, in other words, on sulfur requirements per day.

Depending on combustion chamber

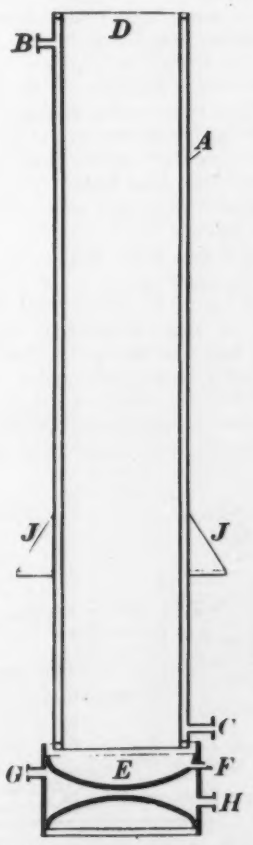

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Figure 11—CIL tubular sulphur melter.

size and fan capacity, a 5 feet by 15 feet burner will burn from 18 to 22 tons of sulfur per 24 hours.

Spray Type Sulfur Burner — The quoted material concerning the description of the spray-type sulfur burner is taken from *Pulp and Paper Manufacture* (9).

This type of burner, shown in *Figure 14,* involves the application of a relatively new principle as concerns the burning of sulfur but which is an old one in connection with the combustion of oils, tars and other liquid fuels.

"The method consists of pumping sulfur in the molten state from a melting tank or pit *A* by means of a piston-type, or centrifugal, metering pump *B* through steam-jacketed lines *C* into an atomizing spray-nozzle *D* of the oil burner type. The nozzle is located in one end of a horizontal, stationary, cylindrical, steel combustion chamber *E,* lined with insulating and refractory brick. The chamber is equipped with a series of over- and underpass baffles *G,* located at regular intervals over its entire length, and a burner gas outlet at the back end. An entry port is provided, concentric to the spray nozzle, through which air for combustion is supplied. The sulfur, in a fine state of subdivision due to the atomizing nozzle, burns in suspension in the air as it passes through the combustion chamber. From the outlet of the burner, the sulfur dioxide gas is conducted through *H* to the cooling system," which usually includes a waste heat boiler. This latter equipment is described under "Cooling Sulfur Dioxide Gas."

After a shut down of three or more days, the start up of a spray burner requires up to 16 hours (11). An oil burner is first introduced into the burner and the lining is allowed to heat slowly to prevent sudden expansion. Once the lining at the front of the burner is sufficiently hot sulfur is fed into the spray nozzle and ignited

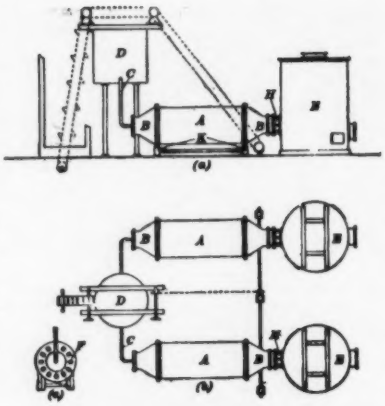

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Figure 12—Diagram of rotary burners.

with the oil torch. The sulfur feed is then gradually increased until full temperature is reached. During these operations the drafts are gradually opened to supply the required air.

Over normal week-end shut downs (16 to 32 hours), the lining of the burner remains red hot and full gas strength can be obtained in about 30 minutes by simply starting the sulfur pumps, the sulfur igniting itself from the heat of the insulating brick.

Only about 15 minutes are required to shut down a spray burner, since it is only a question of stopping the pump supplying the sulfur to the burner. With the sulfur burning in suspension as fed to the burner, it is not necessary, as in the case of rotary burners, to burn a charge of sulfur used to maintain normal operation.

A spray type burner 32 feet long by 10 feet in diameter, having two spray guns equipped with ¾ inch spiral shanks and 3.5 millimeter orifices, will burn up to 45 tons of sulfur per day.

The main advantages of spray burners over other types of sulfur burners are:

(1) Simplicity of operation.

(2) Ease of start ups and shut downs.

(3) Higher strength of burner gas.

(4) Reduction of sulfur trioxide formation and elimination of sublimed sulfur.

(6) *Combustion Chamber*—This piece of equipment is not used with spray type burners, since these burners are in effect combustion chambers with the sulfur being burned as soon as it enters the burner. Combustion chambers are used, however, on other types of burners, particularly rotary burners, to assist in avoiding sublimation by completing the combustion of the sulfur.

The combustion chamber, shown in *Figure 15,* is simply a large steel chamber lined with brick that is backed with fire clay. It is located close behind the burner and the gases are intimately mixed in it. The dampers for admission of the secondary air are located between the burner and the combustion chamber. The combustion chamber has also one or more baffle plates or walls to hold back dust particles and to ensure effective mixing of the gases. Combustion chambers should be large to permit a higher percentage of sulfur dioxide in the gas, without danger of carrying over sublimed sulfur.

A combustion chamber 10 feet high by 7½ feet in diameter will have sufficient capacity to supplement a 15 feet by 5 feet rotary burner burning 18 tons of sulfur per day.

2B. Production of Sulfur Dioxide by Burning Pyrites

(1) *Pyrites* — The quoted material concerning the description of pyrites is taken from *Acid Making in the Sulphite Pulp Industry* (1).

"FeS_2 is an insoluble yellow to brown naturally occurring sulphide of iron which, according to the formula, contains 53.45 percent sulfur and 46.55 percent iron. It is, however, seldom found in nature in this high purity.

"The pyrites used should contain no less than 40 percent sulfur; 50 percent sulfur content pyrites is obtainable as a flotation by-product. To be satisfactory, pyrites should be nearly free from lead, zinc, antimony, arsenic and selenium. Regarding the last two, it is well known that the presence of even very small quantities may cause serious trouble in the sulphite cooking process."

The cost of pyrites burning as compared with sulfur, varies from mill to mill depending on: (a) the costs of sulfur and pyrites respectively, (b) the distances from the mill, at which both materials are available and, (c) the distance from the mill where outlets for the iron oxides produced are avail-

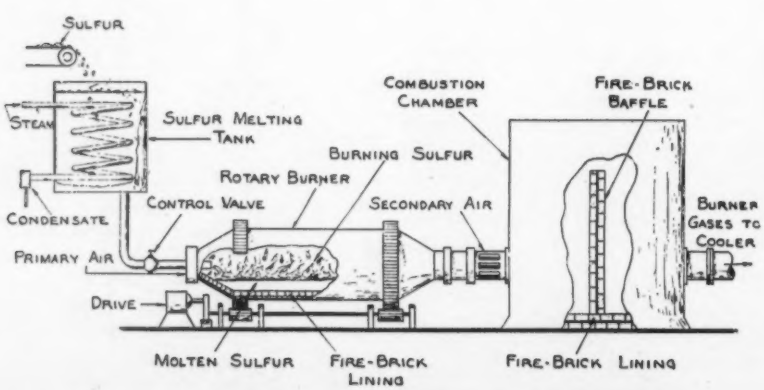

Figure 13—A Rotary Sulphur Burner and Combustion Chamber System.

able and, (d) the price received for the iron oxides.

At the present, because of the plentiful supply of very pure sulfur available in the United States, the use of pyrites is more attractive to Canadian mills than to American mills.*

The high maintenance costs of pyrites burners and the difficulty in removing dust from the gas produced from pyrites are two reasons why the burning of sulfur is preferred, even in Canada.

One definite advantage in pyrites burning in mills equipped with heat recovery systems is the greater amount of heat liberated in burning pyrites. Burning 200 pounds of pyrites containing 50 percent sulfur will yield 549,000 B.T.U., while burning 100 pounds of sulfur will yield only 398,000 B.T.U.

(2) *Chemistry and Calculations of the Pyrites Burning Process*—Editor's Note: The following theoretical calculations have been taken from A. N. Lunberg's book, "Acid Making in the Sulphite Pulp Industry" (1) with minor modifications and rearrangements by the author.

When burning pyrites in air sulfur dioxide is formed according to the following equations:

(a) $2FeS_2 + 5\frac{1}{2}O_2 \rightarrow 4SO_2 + Fe_2O_3$
(b) $3FeS_2 + 8O_2 \rightarrow 6SO_2 + Fe_3O_4$

(a) Assuming air to be 79 percent nitrogen and 21 percent oxygen, the equation (a) indicates that 5½ volumes of oxygen carry:

$5.5 \times 79/21 = 20.69$ volumes nitrogen

and the theoretical possible gas, therefore, will consist of

4	volumes	SO_2
20.69	volumes	N_2
24.69	volumes	gas

and 4 volumes SO_2 are $4/24.69 \times 100 = 16.20\%$, by volume.

(b) Assuming air to be 79 percent nitrogen and 21 percent oxygen, the equation (b) indicates that 8 volumes of oxygen carry:

$8 \times 79/21 = 30.09$ volumes nitrogen

and the theoretical possible gas, therefore, will consist of

6	volumes	SO_2
30.09	volumes	N_2
36.09	volumes	gas

and 6 volumes SO_2 are $6.00/36.09 \times 100 = 16.63\%$, by volume.

As in the sulfur burning process, it is next to impossible to obtain the theoretical sulfur dioxide concentration when burning pyrites. It should be possible, however, to produce a burner gas consisting of at least:

11%	SO_2
7%	O_2
82%	N_2
100%	gas

The above combination of the burner gas from pyrites burning is derived from the following calculations:

(a) $2FeS_2 + 5\frac{1}{2}O_2 \rightarrow 4SO_2 + Fe_2O_3$

	Mols. O_2
SO_2 in gas assumed 11%, thus	11.00
O_2 to Fe_2O_3, thus $11 \times \frac{5.5-4}{4}$	4.13
	15.13

$\frac{15.13 + O_2}{N_2} = 21/79$ and $11 + O_2 + N_2 = 100$

Hence:

O_2 =	6.93%
N_2 =	82.07%
SO_2 =	11.00%
	100.00%

(b) $3FeS_2 + 8O_2 \rightarrow 6SO_2 + Fe_3O_4$

	Mols. O_2
SO_2 in gas assumed 11%, thus	11.00
O_2 to Fe_3O_4, thus $11 \times \frac{8-6}{6}$	3.67
	14.67

$\frac{14.67 + O_2}{N_2} = \frac{21}{79}$ and $11 + O_2 + N_2 = 100$

Hence:

O_2 =	7.15%
N_2 =	81.85%
SO_2 =	11.00%
	100.00%

Averaging:

O_2 =	7.04%
N_2 =	81.96%
SO_2 =	11.00%
	100.00%

Based on 100 pounds sulfur.

Pyrites Burning with Dry Air and No. SO_2 Formation

Burner Gas		Molecular Weight	Pounds in One Molal Volume	Percent by Weight
11.0%	SO_2	64	7.04	21.8
7.0%	O_2	32	2.24	7.0
82.0%	N_2	28	22.96	71.2
100.0%	gas		32.24	100.0

Thus:

SO_2 by weight = 21.8%

Total weight of burner gas = $\frac{200}{0.218} = 917$ lbs.

Total volume of burner gas = $\frac{200 \times 359}{64 \times 11} = 10{,}200$ cu. ft.

1 cu. ft. burner gas = 0.0899 lbs.

1 lb. burner gas = 11.10 cu. ft. (See *Figures 16 and 17*)

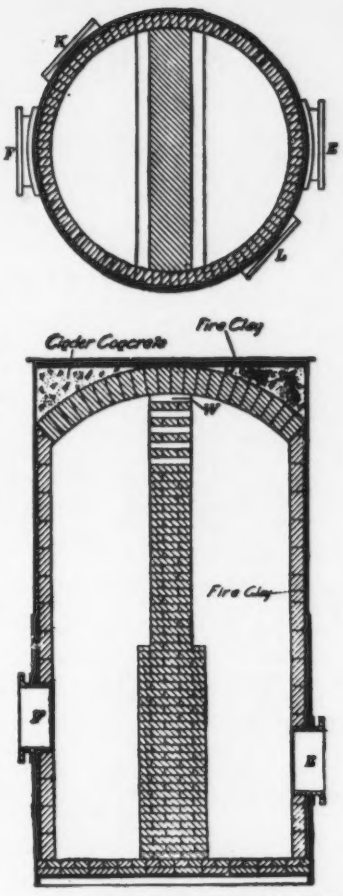

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Figure 15—Combustion chamber.

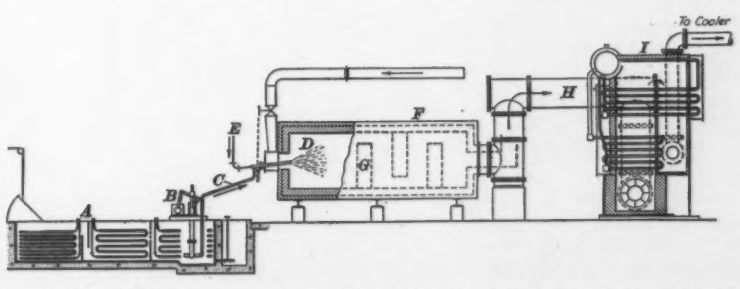

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Figure 14—Spray-type sulphur burner.

* This paper was presented before the present sulfur shortage developed.

Pyrites Burning with 2.8 Percent Water Vapor and No SO_2 Formation

Burner Gas	Molecular Weight	Pounds in One Molal Volume	Percent by Weight
10.7% SO_2	64	6.85	21.5
6.8% O_2	32	2.18	6.8
79.7% N_2	28	22.32	70.1
2.8% H_2O	18	0.50	1.6
		21.85	100.0

Thus:

SO_2 by weight = 21.5%

Total weight of burner gas = $\frac{200}{0.215}$ = 930 lbs.

Total volume of burner gas = $\frac{200 \times 359}{64 \times .107}$ = 10,480 cu. ft.

1 cu. ft. burner gas = 0.0888 lbs.

1 lb. burner gas = 11.25 cu. ft.

(3) *Thermochemistry of the Pyrites Burning Process*—Calculations based on 200 lbs. of pyrites, containing 50 percent sulfur; atmospheric pressure = 760 mm Hg.

Final gas: 11.00% SO_2
6.95% O_2
82.05% N_2
100.00% gas

Air (dry) entering at 72°F.

Pyrites entering at 72°F.

Calcines leaving at 1000°F.

Air volume entering 10,575 cu. ft. S.T.P. *(Figure 17)*.

Gas volume leaving 10,182 cu. ft. S.T.P. *(Figure 16)*.

It is assumed the pyrites is roasted to 50 percent Fe_2O_3 and 50 percent Fe_3O_4.

A true iron pyrites (FeS_2) contains 46.55 percent Fe and 53.45 percent S. Thus 100 lbs. sulfur holds 87.10 lbs. iron and actually only 187.10 lbs. true FeS_2 is roasted. The balance of the 200 lbs. of pyrites is gangue.

According to the equations given before:

$$2FeS_2 + 5\frac{1}{2}O_2 \rightarrow Fe_2O_3 + 4SO_2$$
$$3FeS_2 + 8O_2 \rightarrow Fe_3O_4 + 6SO_2$$

Therefore:

$$5FeS_2 \rightarrow Fe_2O_3 + Fe_3O_4$$

Thus, 187.10 lbs. FeS_2 gives 122 lbs. iron oxides which together with 12.9 lbs. gangue makes 134.9 lbs. calcines.

The specific heat of pyrites, iron oxides and gangue is assumed to be 0.20.

The heat of combustion of FeS_2 into Fe_2O_3 is 5568 B.T.U. and into Fe_3O_4 is 5388 B.T.U. per lb. of sulfur present.

If the products of combustion results in a calcine of 50 percent Fe_2O_3 and 50 percent Fe_3O_4, then the heat of combustion is 5490 B.T.U. per lb. sulfur burned or 2745 B.T.U. per lb. SO_2 produced.

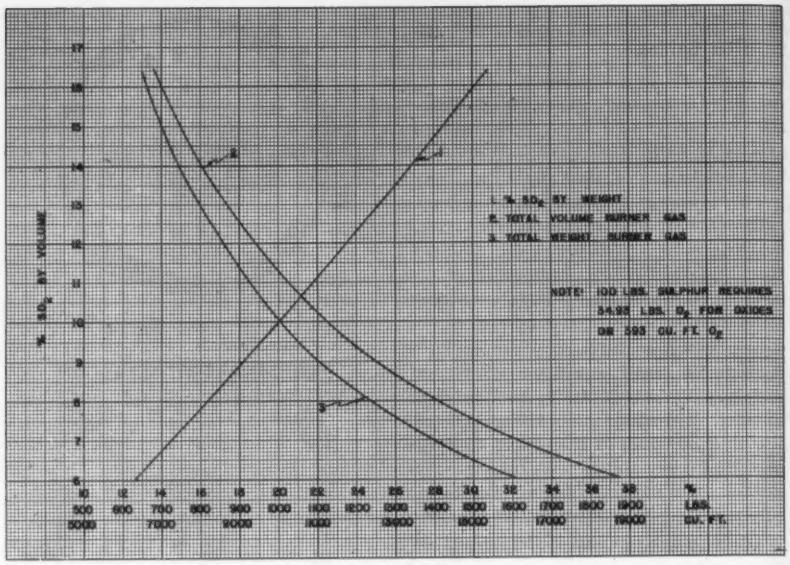
% SO_2 BY VOLUME
1. % SO_2 BY WEIGHT
2. TOTAL VOLUME BURNER GAS
3. TOTAL WEIGHT BURNER GAS
NOTE: 100 LBS. SULPHUR REQUIRES 34.92 LBS. O_2 FOR GASES OR 595 CU. FT. O_2
% SO_2
LBS. SU. FT.

Figure 16—Weight and volume of burner gas at S.T.P. (Based on burning 200 lbs. Pyrites, 50% sulfur; gas dry.)

Heat Input

Heat in pyrites = 200 × 0.20 × (72—32) =	1600 B.T.U.
Heat in air entering = 10575/359 = 29.46 mols. 29.46 × 6.95 × (72 — 32) (See Figure 6) =	8170 B.T.U.
Heat of formation and combustion 200 × 2745 =	549,000 B.T.U.
Total heat input	558,770 B.T.U.

Heat Output

Heat in calcines = 134.9 × 0.20 × (1000—32) =	26,317 B.T.U.
Radiation = 10% of total heat input =	55,877 B.T.U.
Heat in gas leaving =	476,576 B.T.U.
Total heat output =	558,770 B.T.U.

Using the same formula as under "Thermochemistry of the Sulfur Burning Process" the temperature of the combustion gases leaving is as follows:

Volume of gas leaving 10,182 cu. ft. S.T.P.
10,182/359 = 28.36 mols.

SO_2 =	11% by vol. =	3.12 mols × 64.06 =	200 lbs.
O_2 =	6.95% by vol. =	1.97 mols × 32.00 =	63 lbs.
N_2 =	82.05% by vol. =	23.27 mols × 28.18 =	656 lbs.
	100.00% by vol. or 28.36 mols		= 919 lbs.

SO_2 = 200 × (0.145 T + 0.00003T²)
O_2 = 63 × (0.216 T + 0.000014T²)
N_2 = 656 × (0.245 T + 0.000014T²)

SO_2 = 0.00600T² + 29.000 T
O_2 = 0.00088T² + 13.608 T
N_2 = 0.00918T² + 160.720 T

0.01606T² + 203.328 T

0.01606T² + 203.328 T = 476,576 ÷ 1.8
T = 1189° C. *Or* 2172° F.

This temperature is found to be too high for practical operation of certain roasters. Difficulties, such as clinkering of the calcines, occur at a temperature above 1000°C. (1832°F.) in certain roasters.

To control the temperature part of the cooled burner gases is sometimes recirculated. The procedure will be discussed under "Cooling of Burner Gases."

(4) *Pyrites Burners*—The two types of pyrites burners most in use today are the Herreshoff roaster and the Nichols-Freeman flash roaster.

Herreshoff Roaster—The following quoted material concerning the description of the Herreshoff furnace is taken from *Pulp and Paper Manufacture* (9).

"It consists of a steel cylinder *A* lined with red brick *B (Figure 18)*. It is divided by arches *C*, of fire brick, into several compartments, one above the other. The top of each of the arches forms a hearth upon which the ore is burnt.

"The ore is fed from hopper *K* to the top chamber and distributed on the hearth. The rabbles *F* (teeth) serve to convey the ore to the inner section of one hearth and the outer section of the next lower hearth. The cinder is removed at the bottom shelf or chamber."

The hollow central shaft, *D*, and arms are cooled by air, which is in part admitted at the bottom hearth, and materially assists combustion by being warm. The spent cinders contain from ½ percent to four percent sulfur.

"Small size furnaces of about 11 ft. diameter require 1 to 2 hp. and will roast from 3 to 4 tons of pyrites in 24 hr. The larger size furnace, 16 ft. in diameter, will roast about 9 tons in 24 hr."

Considerable time is required to bring this type of roaster to full production, particularly if it has been down long enough for the lining to cool off.

"Before any ore is admitted, the furnace has to be brought to the required temperature for roasting by maintaining a good fire in the furnace" (usually oil fire). "When the desired temperature is reached, the pyrites, which has been drying in the top chamber is gradually fed to the furnace and the air is regulated by means of the dampers as well as by the gas pump or fan."

The heat produced by the oxidation of the sulfur and iron is sufficient for carrying on the operation and once the furnace is in good working condition no fuel is required.

Formerly, the gas was passed through long chambers to remove the dust but today this is usually done by passing the gas through towers into which water is sprayed. These towers which are described further on have the added advantages of removing sulfur trioxide from the gas and also cooling it.

Nichols-Freeman Flash Roaster — The following quoted material concerning the description of the Pyrites Flash Roaster is taken from *Pulp and Paper Manufacture* (9).

Fine iron pyrites concentrates (40 mesh or finer) are roasted while in suspension in air (flash roasting) in this type of roaster, shown in *Figure 19*.

"The dried concentrates are fed from a hopper by vibrating or by a rotary feeder *A* and are mixed with primary air for combustion which also serves to convey the pyrites to the burner nozzle. Grinding of pyrites flotation concentrates is unnecessary, but in some cases, a ball mill *B* is used to break up the lumps formed in storage or drying, and this also ensures thorough mixing of the primary air and pyrites."

The mixture of air and pyrites burns on its way down into the combustion chamber and the gas leaves the top of the combustion chamber for the dust chamber while the calcines fall to the bottom of the combustion chamber from where they are removed by a conveyor.

From the dust chamber the gas passes through a waste heat boiler to cool it down and then to a scrubbing tower to remove any dust left in the gas.

A portion of the cooled sulfur dioxide gas from the boiler is sometimes recirculated back to the fan ahead of the ball mill to the combustion chamber to control temperature and enable high sulfur dioxide gas strength to be maintained.

In starting up this type of roaster, an oil burner is used to raise the temperature of the furnace to a point at which the pyrites will readily ignite. The pyrites is then fed in, the air adjusted and the gas brought up to strength. This operation can be carried out in about three quarters of an hour after a normal week-end shut down.

2C. Use of Liquid Sulfur Dioxide Received in Tank Cars

It was suggested long ago, that sulfite mills might to advantage purchase liquid sulfur dioxide from chemical manufacturers rather than burn sulfur or pyrites to produce sulfur dioxide for manufacturing the liquor used in cooking. The high cost of liquid sulfur dioxide, however, has generally discouraged interest in this possibility.

Recently, however, because of new methods of preparing liquid sulfur dioxide at lower cost, interest in this subject has been revived. It is not unusual, now, for mills to fortify their acid with liquid sulfur dioxide during the periods of warm water. Recently, a full mill scale trial was carried out at the Fort William Division of Abitibi Power & Paper Co., when all the acid used was made with liquid sulfur dioxide.

All we need mention of this subject here, is that liquid sulfur dioxide has a boiling point of 14 degrees Fahrenheit at atmospheric pressure and a latent heat of evaporation of 5960 cal./mol. and it is necessary, therefore, to pass the liquid through a vaporizer to obtain the gas.

The gas obtained from liquid sulfur dioxide must be diluted with inert gas for use in the absorption towers. It has been found that the exhaust from the acid plant towers which is mostly nitrogen and carbon dioxide can be used for this purpose.

3. Sulfur Trioxide Formation

The proper operation of an acid plant demands the minimum formation of sulfur trioxide by oxidation of sulfur dioxide. Any sulfur oxidized to sulfur trioxide represents a direct loss of sulfur since the sulfur trioxide radical reacts with the calcium in limestone to give the insoluble calcium sulfate.

This calcium sulfate can, moreover, be a serious source of trouble in the cooking operation because it will at times precipitate on the chips, prevent-

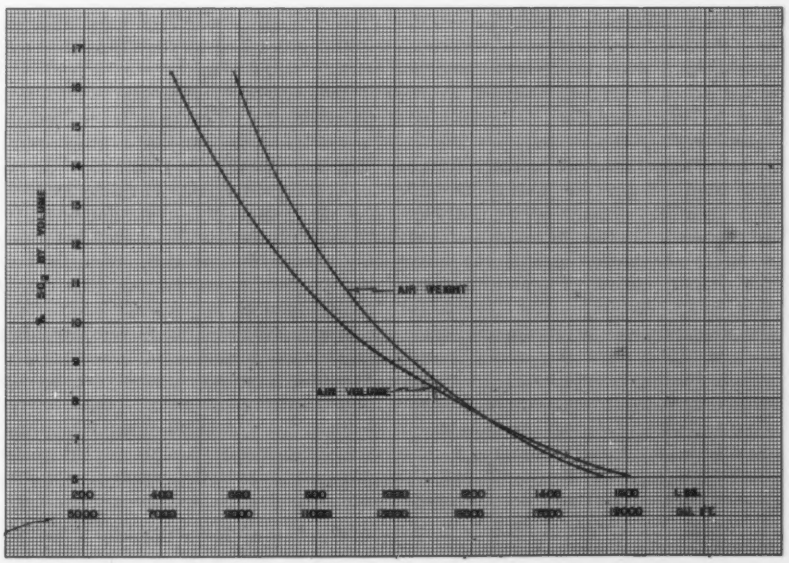

Figure 17—Weight and volume of dry air required to burn 200 lbs. Pyrites (50% Sulfur)

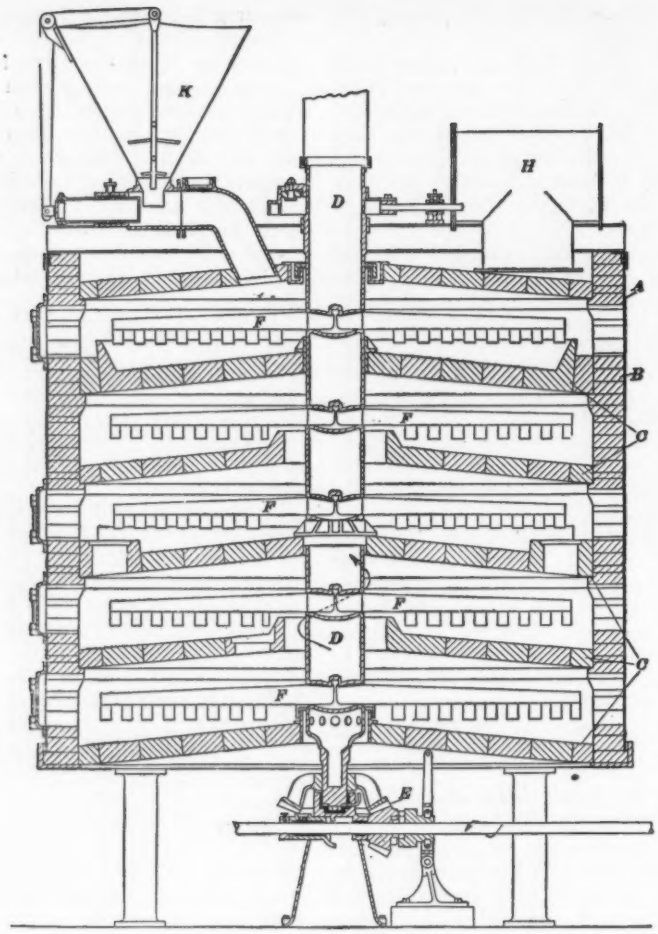

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Figure 18—Herreshoff pyrites roaster.

ing the penetration of the liquor during the cooking, and at other times will form a scale inside pipes and fittings so that acid and steam cannot flow. This condition is known as "Liming."

The importance of correct burner operation to prevent sulfur trioxide formation has already been mentioned. In general, it can be said that the stronger the burner gas is the lesser the chances of sulfur trioxide formation, since less oxygen is present for the oxidation of sulfur dioxide.

It is also known that rapid cooling of the burner gas will help to reduce sulfur trioxide formation. At temperatures about 1000 degrees Centigrade no oxidation of sulfur dioxide to sulfur trioxide takes place, but as the temperature is reduced the formation of sulfur trioxide increases with the optimum being reached around 750 degrees Centigrade. Below this temperature the amount of sulfur trioxide formed again decreases until at about 400 degrees Centigrade no further oxidation takes place.

It is for this reason that every effort is made to cool the gas from 1000 degrees Centigrade to 400 degrees Centigrade as rapidly as possible.

Certain materials, including iron, act as catalysts in the oxidation of sulfur dioxide to sulfur trioxide, but since these materials are required in the construction of an acid plant little can be done about their presence.

Spray type cooling towers are often used as a means of removing sulfur trioxide from the gas before it goes into absorption towers. These towers, which are described under "Cooling" do not prevent the loss of sulfur but they do prevent the "Liming" of pipes and fittings.

4. Cooling of Sulfur Dioxide

It has already been mentioned that it is important to cool the burner gas rapidly to prevent oxidation of the sulfur dioxide to sulfur trioxide. It is also essential to cool the gas to facilitate its absorption in the towers and help in controlling the acid composition.

The coolers should also be as near as possible to the combustion chamber so that the gas will not be kept too long in the critical temperature range for sulfur trioxide formation.

Cooling is accomplished by means of:

A. Pond Coolers
B. Jenssen Horizontal Coolers
C. Spray Coolers
D. Waste Heat Boilers
E. Combination of various methods listed above.

(1) *Pond Coolers* — The following quoted material concerning the description of the pond coolers is taken from *Pulp and Paper Manufacture* (9).

"This *(see Figure 20)* consists of 6 in. lead pipes arranged parallel to one another and connected with flanges to lead headers. The whole system is placed in a pond, with the gas entering at one header, passing through the pipes and leaving at the opposite header, while the cooling water is running in the opposite direction, cooling the outside of the pipes. With good circulation of the water, cooling is fairly effective. But it is obvious that with this method the cooling water is not used to its fullest advantage, since the water closest to the pipe receives most of the heat," and unless violently agitated will warm up rapidly and lose its cooling effect.

(2) *Jenssen Cooler* — The following quoted material concerning the Jenssen Cooler is taken from *Pulp and Paper Manufacture* (9).

"This cooler *(See Figure 21)* is a combination of the submerged, horizontal, pond cooler and a vertical cooler consisting of vertical lead pipes connected at the top by U bends. Water is sprayer onto the pipes at the top and flows down along the pipes, forming a thin film around them. With this cooler, the gas can be cooled nearly to the temperature of the water.

"In *Figure 22,* A shows the course of gas from the combustion chamber; B is a cast iron pipe connecting the main gas header with submerged lead pipes; C, D, are 12-inch diameter lead headers; E, elliptical vertical lead pipes; F, pipe to acid system; G, water seals; H, water spray boxes; I and J, quick-opening flanges."

The water seals, G, and quick-opening flanges, I and J, are opened during plant shut downs to permit hosing down sublimed sulfur adhering to the inside of the pipes. The amount of sulfur found inside the coolers will vary with the efficiency of operation

of the burner but it may be considered standard practice to wash coolers once a week.

Coolers are washed to prevent carry-over of sublimed sulfur to the cooking acid in which its presence is very detrimental to pulp quality. Moreover, if the sulfur is allowed to accumulate in the coolers it reduces the cooling efficiency and will reduce the acid plant capacity by increasing the friction loss in the coolers.

It is obvious that since the coolers are made of lead (melting point about 625 degrees Fahrenheit) and the burner gas is at 1800 degrees Fahrenheit to 2500 degrees Fahrenheit water must be kept on the coolers at all times to prevent them from melting. Auxiliary sources of water are usually provided in case the regular mill water supply should be shut down suddenly.

Alloys of tellurium and lead are often used today for the manufacture of pond and Jenssen coolers. These have higher melting points than that of lead and are more resistant to deformation so that there is less danger of pipes collapsing when the system is under vacuum.

Cooling area for this type of cooler if used alone, should be 125 to 150 square feet per ton of sulfur burned per day.

(3) *Spray Coolers* — The following quoted material concerning spray coolers is taken from *Pulp and Paper Manufacture* (9).

Various types of spray coolers are now in use. The simplest kind consists of 48 inch outside diameter cast iron pipe lined with acid resistant brick. The hot gas enters near the top where it meets a spray of cold water. The cooled gas leaves at the bottom while the water is discarded to the sewer.

If the volume of water used in this type of cooler is sufficiently small (15-20 U. S. gals./min.), the temperature of the discarded water is sufficiently high to prevent any amount of sulfur dioxide from going into solution in it and the sulfur dioxide loss is very low.

An improvement on this method consists in recirculating the cooling water to the top of the tower after passing it through a heat exchanger to cool it. In such systems, it is necessary to bleed off some water and add make-up water so that the sulfur trioxide content of the cooling water does not exceed 10 percent. Best absorption of the sulfur trioxide from the gas is obtained with water containing about 10 percent sulfur trioxide.

A more elaborate use of the spray cooling principle is illustrated by the Kimberly-Clark Spray-Type Sulfur Dioxide Cooler in *Figure 22.*

"This system consists of two towers, a heat exchanger, a circulating pump and a weir box for water-level control. Both of the towers may be made of chrome nickel corrosion-resisting steel. A water cooled collar connects the gas inlet fitting and the top of the first or primary tower A, and the collar and upper portion of the tower being lined with brick or tile. For inspection and repairs a manhole is provided below the lining. The secondary tower C, which is considerably larger than the other, is fitted with ceramic or wood slat packing, and manholes are provided for access both above and below the packing. The connection between the two towers is made with a removable section and is lined with acidproof tile.

"Hot gas I from the combustion chamber enters at the top of the primary tower A and, as it travels down through the tower, is sprayed with cooling water. When the gas comes in contact with the spray, the temperature of the gas is instantaneously dropped through the critical range of sulfur trioxide formation to the wet-bulb temperature of the gas. Most of the sulfur trioxide which may be present is absorbed by the cooling water which collects at the bottom of the tower where the level is controlled by means of a weir box B, the overflow going to the sewer. Very little SO_2 is retained by the water to the sewer, and results from actual operation show that the loss is less than 1 lb. of sulphur per ton of pulp.

"The gas, cooled to approximately 155° F., passes into the lower portion of the secondary tower C, where it is met with another spray, completing the cooling. As the cooling water from this tower carries some SO_2, it is passed through a heat exchanger D and the cooled water recirculated through the tower. Part of this water, however, is used for the spray in the first tower via pipe E. Line F carries cooling water for heat exchanger D. To maintain the water level in the secondary tower, make-up water G is added in the weir box from the water-cooled collar on the primary tower, and with normal operation the flow is always into the tower. Cool, washed gas is discharged through pipe K to the acid-absorption towers.

"In case of either power failure or stoppage of the circulating pump for any reason, a safety switch and solenoid-operated valve H are so arranged that the valve will open a fresh water supply for the spray in the primary tower to prevent damage to the equipment from overheating. Cooling at this time in the second tower is through a manually controlled valve in the cold-water supply.

"As previously stated, connections are made from both towers to a weir box. This box is fitted with a hood so that any gas which may be released can be removed through a vent. While sublimation has no effect on the operation of the system its presence can be detected immediately by the condition of the water in the overflow from the primary tower. An observation glass is provided in the hood for inspection purposes.

"The system occupies very little space, is free from leaks, and all connections are easily accessible. Loss in SO_2 is

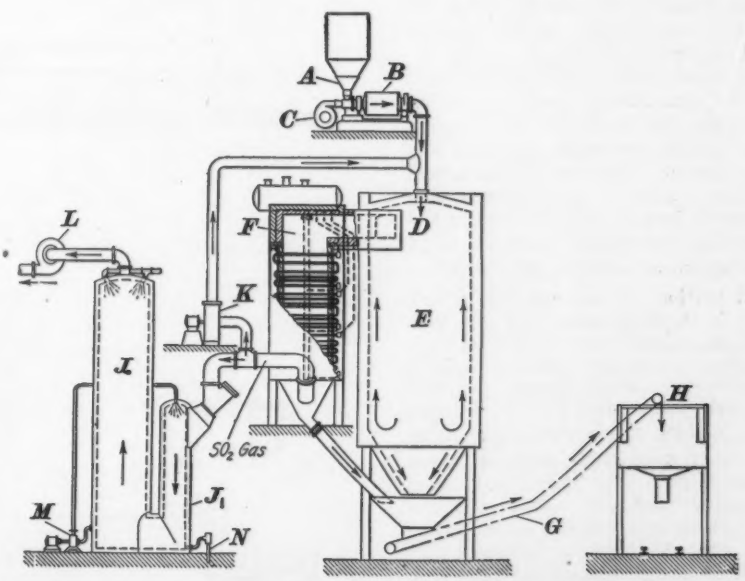

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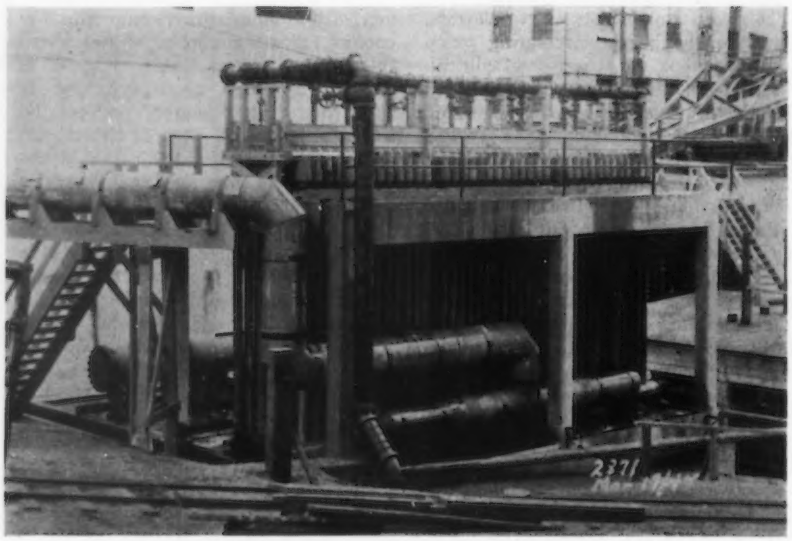
Figure 19—Pyrites flash roaster.



Courtesy G. D. Jenssen Co., New York

Figure 20—Jenssen lead gas cooler installation.

The steaming elements are grouped in sections, each of which has an independent water and steam circulation system. Water is fed to the bottom header of each section from a large downcomer manifold. Steam generated and heated water flow directly to the drum through connector tubes leading from upper headers of each section to the drum. All these steam carrying risers enter the drum above the water line to aid in delivery of dry steam.

The cast iron extended surface of each element can be made in various diameters and shapes even though the size and length of the steel tube is kept the same. Thus the amount of heat absorbing surface can be varied. This provides the flexible construction necessary for the proper handling of the varying gas conditions found in any one installation. This heat absorbing area is much greater per lineal foot of element and per cubic foot of space occupied than with bare tubes of the same diameter. Elements in the

extremely low, and the rapid preliminary cooling reduces the formation of SO_3, the greater percentage of which is absorbed by the spray in the first tower."

(4) *Waste Heat Boiler* (4) (13)—A commonly used waste heat boiler today is illustrated by Figure 23. It accomplishes the double purpose of absorbing heat from the gas and generating useful steam from the waste heat. Between 3 and 3.5 pounds of saturated steam at 105 pounds gauge per pound of sulfur burned are obtained.

It is necessary to guard against corrosion from certain concentrations of sulfuric acid which rapidly destroy steel. In the Foster-Wheeler sulfur dioxide waste heat boiler shown here, this is accomplished by construction featuring the armored design, cast iron covered, steel tube, extended surface element. This element has a heat absorbing surface several times that of steel tubing of the same length and permits concentrations of large amounts of surface in a small space.

All portions of the elements which come in direct contact with the gas, or might possibly come in contact with the gas, are cast iron encased. Where elements pass out of the gas duct, the steel tube has a rolled joint in the tube sheet making it completely gas tight. All other steel parts such as steam drum, headers, and water and steam connector tubes are outside the gas flow where they will not come in contact with sulfur gas or unburned particles of sulfur. Should any joint leak the water would fall outside of the gas chamber.

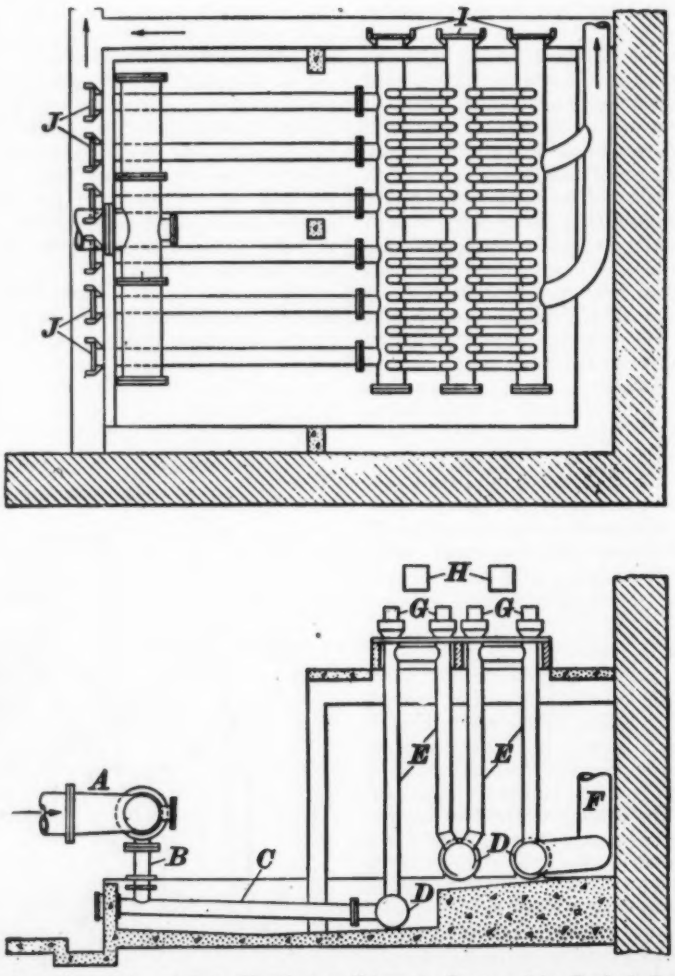


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Figure 21—Jenssen SO_3 cooler.

TABLE I

HEAT BALANCE IN WASTE HEAT BOILER *(13)*
Based on 100 lbs. sulphur burned

Heat Gained By The System		*Heat Lost By The System*	
1. *Heat in 100 lbs. melted sulphur*		1. *Heat in cooled burner gas*	
Heating from 32° to melting point		Burner gas volume = 6369 cu. ft. S.T.P.	
100 × (235 — 32) × 0.1728	3508 B.t.u.	SO_2—17.6% × 6369 × 0.1786 = 200 lbs.	
Latent heat of fusion 100 × 16.86	1686 B.t.u.	200/64 × 9.84 (585 — 32)	17,005 B.t.u.
Heating liquid to 300° F.		N_2—78.3% × 6369 × 0.0781 = 389.5 lbs.	
100 × (300 — 235) × 0.235	1527 B.t.u.	389.5/28.01 × 7.08 × (585 — 32)	54,450 B.t.u.
Total	6721 B.t.u.	O_2—3.2% × 6369 × 0.0891 = 19.3 lbs.	
		19.3/32 × 7.08 × (585 —32)	2,221 B.t.u.
2. *Heat in combustion air entering*		1.18 lb. water is 1.18/18 mols.	
Total weight of air entering = 515 lbs.		1.18/18 × 8.50 × (585 — 32)	308 B.t.u.
Oxygen 23.1% by wt. = 118.9 lbs.			73,984 B.t.u.
118.9/32 = 3.71 moles.			
Nitrogen—76.9% by weight = 396.1 lbs.		2. *Radiation*	
396.1/28.18 = **14.05 moles.**		Unaccounted for (by difference)	9,244 B.t.u.
(14.05+3.71) × (50—32) × 6.95	2221 B.t.u.		
3. *Heat in atmospheric moisture entering*		3. *Heat in steam produced*	
30/100×0.00764×515=1.18 lbs. water		319.4 lbs. stem produced/ 100 lbs. sulphur	
1.18/18.02 = 0.066 mols.		319.4 × 1190	380,006 B.t.u.
0.066 × (50 — 32) × 8.25	10 B.t.u.		
4. *Heat of combustion*		4. *Heat in blow down (to sewer)*	
100 × 3983	398,300 B.t.u.	Blow down is 20 lbs./100 lbs. sulphur	
		20 × (341 — 32)	6,056 B.t.u.
5. *Heat in boiler feed water*			
339 lbs. water at 210° F/100 lbs. sulphur			
339 × 1 × (210 — 32)	62,038 B.t.u.		
Total Heat Gained	469,290 B.t.u.	Total Heat Lost	469,290 B.t.u.

zones of highest gas temperature may have relatively less total surface than those in cooler zones.

Experience has also shown that the compactness of the extended surface design and the relatively short length of gas travel result in quick cooling of sulfur dioxide gas. This, in turn, retards the formation of sulfur trioxide from reaction between sulfur dioxide and excess air used in combustion.

Where gases are under negative pressure, the boiler casing may be rectangular, flat plate design. For gases under positive pressure a circular shell, such as in the unit illustrated here, is used. All joints may be inspected, tightened and tubes internally cleaned without entering the gas passage.

Figure 23 shows a heat balance in a heat exchanger of this type, located after a spray type burner. In such installations all gas pipes are lined with fire brick to conserve heat.

Since the gas leaves the waste heat boiler at 420 to 550 degrees Fahrenheit depending on the installation, additional coolers are required in conjunction with waste heat boilers.

In practice, it will be found that most mills use a combination of the various pieces of equipment described above to cool the burner gases and that practically no two systems are alike.

It should be borne in mind, however, that if spray type coolers are used, the gas will be saturated at the final cooling temperature, and will, therefore, contain much more heat for a given temperature, than gas which has not been through spray coolers. This is of importance in the absorption process.

5. Gas Fans

A paddle type fan is located after the coolers. This fan keeps the system under a vacuum of a few inches of water from the burner up to the fan and under a similar pressure from the fan to the absorption system.

Fans are usually either rubber lined or made out of lead or chrome-nickel steel for protection against corrosion.

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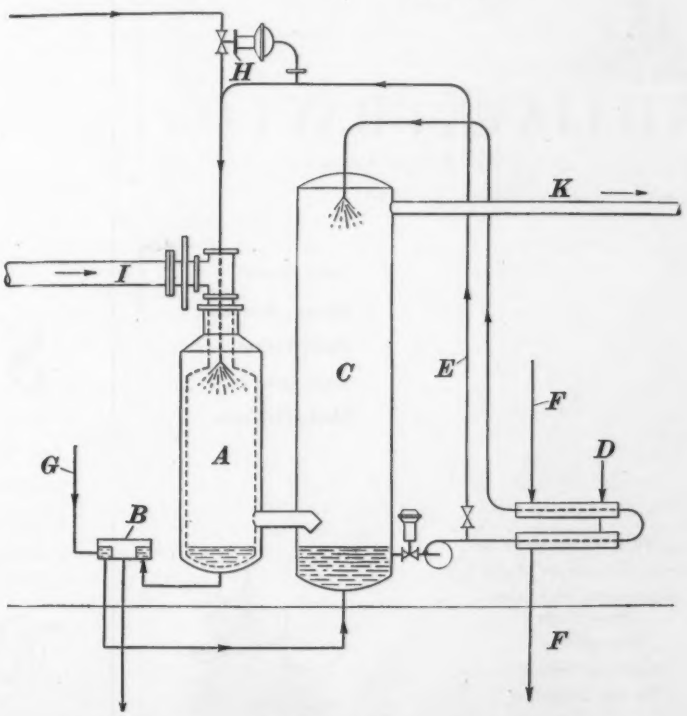

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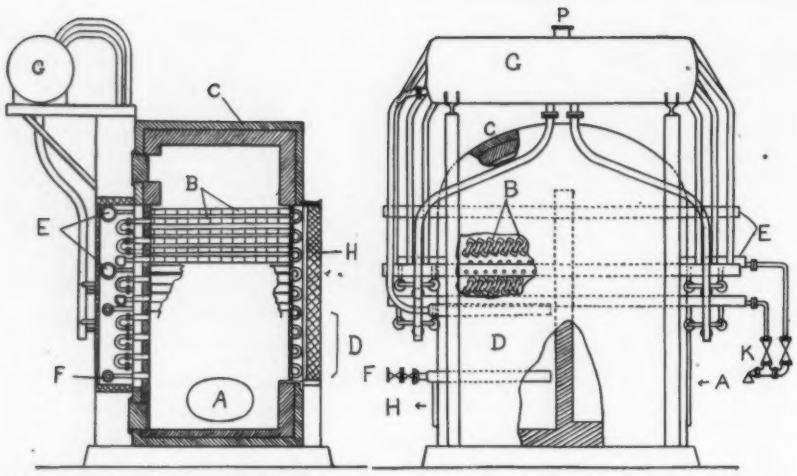
Figure 22—Chemipulp—Kimberly Clark spray cooler.



Courtesy *Pulp and Paper Magazine of Canada*

Figure 23

Waste heat boiler (side elevation)

LEGEND
A—Gas Outlet
B—Cast Iron Gilled Rings
C—Insulating Brick
D—Economizer Section
E—Steam Headers
F—Feedwater Inlet
G—Steam Drum
H—Rockwool

Waste heat boiler (front elevation)

LEGEND
A—Gas Inlet
B—Cast Iron Gilled Rings
C—Insulating Brick
D—Economizer Section
E—Steam Headers
F—Feedwater Inlet
G—Steam Drum
H—Gas Outlet
H—Gas Outlet
K—Blowdown Valves
P—Steam Outlet

(7) "Modern Pulp and Paper Making," (2nd Ed.), Witham, G. S., Sr., New York, Reinhold Publishing Co., (1942).

(8) "New Developments in the Sulphite Industry," C.P.P.A. Tech. Section, Sulphite Committee, Pulp and Paper Magazine of Canada, 48, No. 1, p. 79-84, (Jan., 1947).

(9) "Pulp and Paper Manufacture," (Vol. I) Preparation and Treatment of Wood Pulp," Stephenson, J. N., New York, McGraw-Hill Book Co., (1950).

(10) "Recovery of Heat from SO_2 Gas," Pulp and Paper Magazine of Canada, 40, No. 5, p. 302-4, (April, 1939).

(11) "Sulphur Spray Burner Operation," Murchie, R. B., Pulp and Paper Magazine of Canada, 45, No. 13, p. 957-958, (Dec., 1944).

(12) "The Use of Liquid Sulfur Dioxide for Calcium Bisulphite Acid Production," Longheed, E. H., Proc. Tech. Sections C.P.P.A., 1948: p. 224-231; Pulp and Paper Magazine of Canada, 49, No. 3, p. 215-221, (Feb., 1948).

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Sulfite Pulping
Sulfur Dioxide Preparation

Everett C. Uebrick[1]

Started in the control laboratory of the Kimberly Clark Co. at the Niagara, Wis. mill in 1920, and was sent to the new mill at Kapuskasing, Ont. as Control Stations foreman in 1923, staying through 1925. From 1926 through 1929 he worked at various operating jobs at the Dells Paper and Pulp Co., Eau Claire, Wis.; Consolidated Water Power and Paper Co., Wisconsin Rapids, Wis.; Port Alfred Pulp and Paper Co., Port Alfred, Que.

In 1930 he went to the Dunn Sulphite Paper Co. at Port Huron, Mich., in charge of the laboratory and stock preparation. In 1943 with the Port Huron Sulphite and Paper Co., for two years on pulp research, two years as chief chemist, and then on through 1949 as technical superintendent of the sulphite mill.

From 1950 to date he has been with the St. Croix Paper Co. as chief chemist and sulphite superintendent.

Sulfur

Sulfur as we generally know it in American sulfite mills is a very pure product obtained by the Frasch process from deposits on the Gulf Coast. These deposits and method of mining are shown in *Figures 1 and 2.*

It melts at 112.8 degrees Centigrade, becomes more fluid with increasing temperature to about 150 degrees Centigrade and by about 160 degrees Centigrade is of very high viscosity. Somewhere between 230 and 260 degrees Centigrade it thins out again and boils at 444.6 degrees Centigrade. When it burns, it combines with the oxygen of the air to form oxidation products, mainly sulfur dioxide. The purity of the gas, the percentage of sulfur dioxide present, is dependent on the conditions under which oxidation is permitted to take place. These conditions are, the proportions of air and sulfur vapor present, the thoroughness with which they are mixed, and the temperature at which they are united.

Flat Burner

Thirty or forty years ago, there were quite a few very simple acid plants. This very simple acid plant consisted of a so-called flat burner, see *Figure 3,* a small cylindrical tank mounted directly over it to serve as a combustion chamber, and, from the combustion chamber, a length of 12 inch cast iron pipe which ran up in the air about 75 feet and then back down to enter the base of the absorption tower. The burner was a box-like affair, about three and a half feet wide, nine feet long, with a sloping bottom which gave a height of about 12 inches at the ends and 18 inches at about three feet from the front. There was a door at the front end which could be lifted up, and an eight inch pipe connection bolted to the top at the back end, discharging into the combustion chamber. A slide on the door at the front and a collar around the gas pipe at the back gave control over the air volume.

As regular operating procedure, every hour the acid maker would open the door in the front of the burner and throw in 70 or 80 pounds of sulfur. This would cool off the molten sulfur in the burner and take 12 to 15 minutes to melt. These burners could be set to make a gas of 14 to 15 percent sulfur dioxide, which they would do for 40 minutes or so out of the hour. But when they were cooled off by having the cold lump sulfur thrown in, the proportion of air to sulfur vapor would change, due to the smaller amount being evaporated, and the sulfur dioxide content of the gas would drop to eight or ten percent. The fact that the gas was cooling as it went through approximately 150 feet of pipe meant that it was heavier on the tower or cold stack side than it was on the hot stack side. This, coupled with the low velocity obtained by the chimney effect obtained in the open topped absorption tower, gave a fine chance for any heavy material, such as sulfuric acid or sublimed sulfur to settle out. That made it possible to have a cooking liquor with less than one gram per liter of sulfate present. However, the stacks had to be cleaned out at least once a week, and sometimes oftener.

The burner had to function first as a melter, to convert the solid sulfur to a liquid, then as an evaporator, to convert the liquid sulfur to a vapor, and then as a burner, to convert the vapor to sulfur dioxide. As it is obviously impossible for one piece of equipment to perform all of these functions efficiently, and as the capacity of the flat burner was less than a ton of sulfur per day, I doubt if any sulfite mill on our continent still uses them.

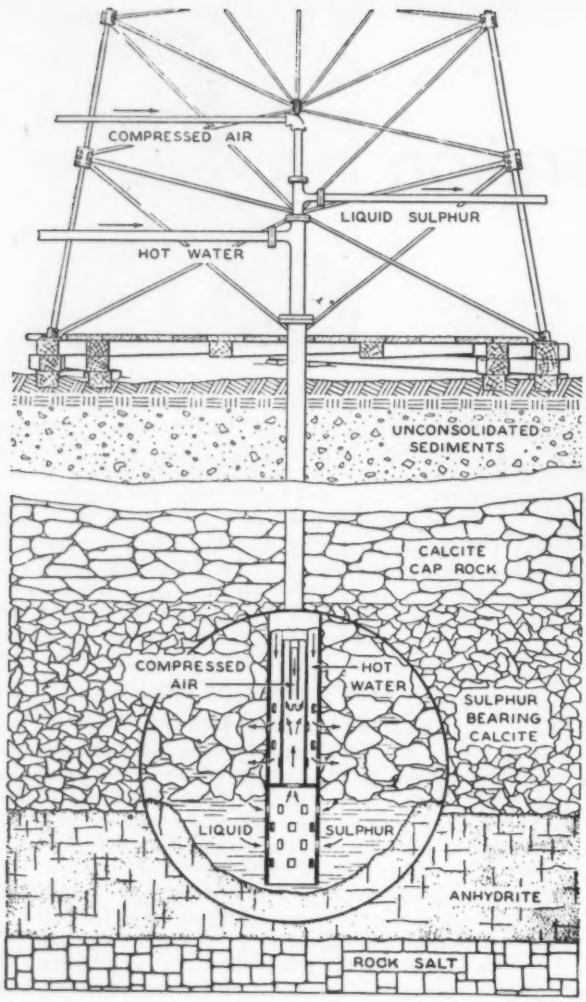
Modern Sulfur Melter

Remembering the physical characteristics of sulfur, we can use them in separating the functions of this simple acid plant among the various pieces of modern equipment. In the modern acid plant, we split up the various jobs between a melter, a rotary vaporizer and combustion chamber or a spray burner, a cooler of the pond, Jenssen, or spray type, and a gas fan or pump.

The sulfur melter can be any shaped iron or steel tank, lined or unlined, but it should be equipped with steam coils to heat and melt the sulfur. It should have a capacity to hold at least enough sulfur for eight hours' operation. Very commonly, it is a vertical cylinder with a conical bottom, the steam coils being around the circumference of the bottom half or two-thirds of the tank. The tank can be elevated so that the sulfur flows out of the bottom of the tank by gravity through a steam jacketed pipe to the sulfur burner or vaporizer. Or, the tank can be below the operating floor level, from which point the molten sulfur is transferred to the vaporizer by means of a pump. By putting a thermometer bulb in the sulfur stream leaving the melter, a controller unit can then be used to actuate the valve controlling the steam input to the melter, and the temperature will thus be held close to 115 degrees Centigrade, where the sulfur will be at its most fluid state.

A very popular melter in Canada just now is the Hamilton melter. This is a vertical, steam jacketed tube. The dry sulfur is fed automatically by con-

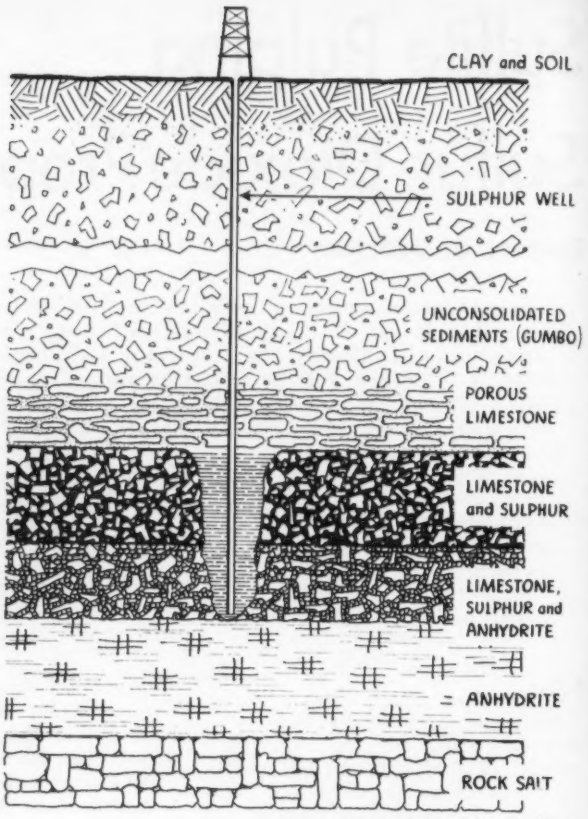
[1] Sulfite Superintendent, St. Croix Paper Co., Woodland, Maine.



SKETCH SHOWING SULPHUR-WELL PIPING

Courtesy Texas Gulf Sulphur Co., Inc.

Figure 1—Well Arrangement



Courtesy Texas Gulf Sulphur Co., Inc.

Figure 2—Sulphur Deposits Underground

veyor or from an overhead bin to keep the tube full, the sulfur melts as it drops down the tube, and the molten sulfur flows as required to keep the storage tank filled. An advantage in separating the melting function from the molten storage lies in keeping the molten storage at a uniform temperature. Again the temperature in the molten storage is controlled to keep the sulfur in its most fluid state, and it is run off through a steam jacketed pipe to the sulfur vaporizer. The melters of this type which I have seen were operating with steam at 75-80 pounds, and doing a nice job of melting about 20 tons of sulfur a day.

Rotary Burner

The most commonly used equipment for vaporizing the sulfur is the rotary burner. This again is a horizontal cylinder, varying in diameter from three to five feet, and in length from eight to fifteen feet for the cylindrical portion. These dimentions will vary according to the capacity needed, but a single three by nine burner which is operated at top capacity will probably take care of the requirements of a one hundred ton sulfite mill. Both ends of the burner are conical, and the whole is rotated on trunnions. The speed of the rotation will be somewhere between one and two revolutions per minute, depending on the diameter of the burner and the rate at which it is desired to burn sulfur. With the high temperature in the burner, the molten sulfur is rather viscous, and will cling to the inner side of the burner as it revolves. The rate of rotation, then, should be so set that the sulfur is just about burned off of the shell by the time that that portion of the burner shell again enters the pool of molten sulfur.

The front of the burner is equipped with a shutter arrangement so that the amount of air entering the burner can be regulated. The pipe carrying the molten sulfur enters here. There is usually an air bubble pipe for a level control apparatus to operate the steam jacketed valve on the sulfur pipe. As a variation in the level of the molten sulfur means a variation in the amount of sulfur surface exposed to the air, the rate of burning can be varied by raising or lowering the sulfur level, as well as by changing the fan speed. Actually, the sulfur level and fan speed are usually used to control the burning rate, and the front draft is left wide open, for regular operation. When burning down, with the sulfur supply shut off, the exposed surface area constantly increases, so that it is then necessary to progressively close off the front of the burner to control the rate of vaporization.

As sulfur vaporizes at 444.6 degrees Centigrade, it can pass off from the vaporizer as gaseous sulfur. If a corresponding amount of air is thoroughly mixed with the gaseous sulfur, it can combine with the oxygen as sulfur dioxide. Since air contains about 20.7 percent oxygen, it should therefore be theoretically possible, by mixing the proper amount of air with vaporized sulfur at a high temperature, to pro-

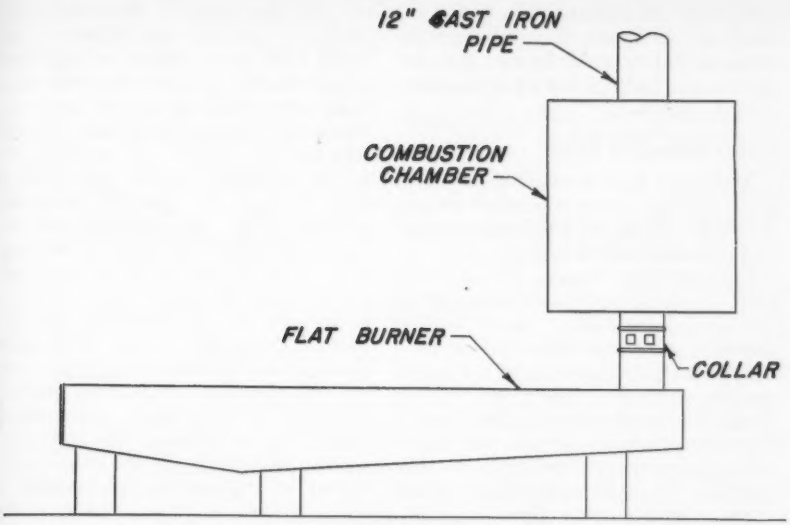


Figure 3—Carthage Flat Burner

duce a gas containing 20.7 percent sulfur dioxide. If a greater proportion of air is admitted the sulfur dioxide can combine with the additional oxygen giving sulfur trioxide. On the other hand, if an insufficient quantity of air is admitted to complete the combustion of all of the sulfur which has been vaporized, the excess vaporized sulfur will sublime when the temperature is lowered and, if in sufficient quantity, load up the coolers, the fan, or even carry over into the absorption system.

The rear cone of the burner is connected by a pipe to the combustion chamber. Immediately after the burner there is an auxiliary draft which can be regulated to supply additional air. The pipe between the combustion chamber and the burner should be arranged so that the gas passes through several "tees" after the auxiliary air is admitted, each change in direction of flow insuring more mixing of the vaporized sulfur with the air before entering the combustion chamber.

Combustion Chamber

The combustion chamber is a large steel chamber which is lined with a high temperature resistant brick which is preferably backed with several inches of mineral insulation. It may be round or rectangular, having one or two baffle walls with checker work in the baffle walls being arranged in such a manner as to insure a thorough mixing of the gases.

The gas leaving the combustion chamber goes through a cast iron pipe to the coolers. It is advisable to insert a thermocouple in the pipe as close to the combustion chamber as possible, to measure and record the temperature of the gas leaving the combustion chamber. The temperature should be close to 1000 degrees Centigrade to inhibit the formation of sulfur trioxide. Also, if it is desired to control the auxiliary air damper automatically, a sample of gas is taken from the hot gas line for the sulfur dioxide analyzer. It is also well, at some convenient spot in the hot gas line, to drill about a quarter inch hole which can be kept closed with a tapered rod but into which a cold glass rod can be inserted as a quick spot-check on sublimation.

Spray Burner

In place of the rotary vaporizer, a few plants have installed the Texas Gulf spray burner. This involves the use of a large combustion chamber, well baffled. Into this, a metering type pump throws melted sulfur which is atomized by a compressed air jet, the sulfur being burned on its way through and around the baffles. As these installations have been well planned to get a thorough mixing of the sulfur with the air, and as the quantities of both sulfur and air can be well controlled, it has been found practicable to run the sulfur dioxide content to 19 or 20 percent without having sublimation troubles. Since the brick walls and baffles hold the heat, the plant can be started up after a 24 hour shut-down and be making a good gas in about a half hour or so. Because there is no pond of sulfur to burn out, the shut-down is practically instantaneous.

Gas Cooling

Immediately after the combustion chamber, it is necessary that the gas be cooled as quickly as possible. The optimum temperature for the formation of sulfur trioxide has been found to be between 600 and 900 degrees Centigrade, while above 1000 and below 400 degrees Centigrade there is practically no formation of sulfur trioxide.

The coolers are generally of three types. The simplest is the pond cooler, in which the gas goes through a series of lead pipes laying parallel in counter current directions.

The Jenssen cooler is a combination of a comparatively small pond cooler with sections, usually two, of vertical pipes. The vertical pipes are connected with "U" bends at the top, each "U"

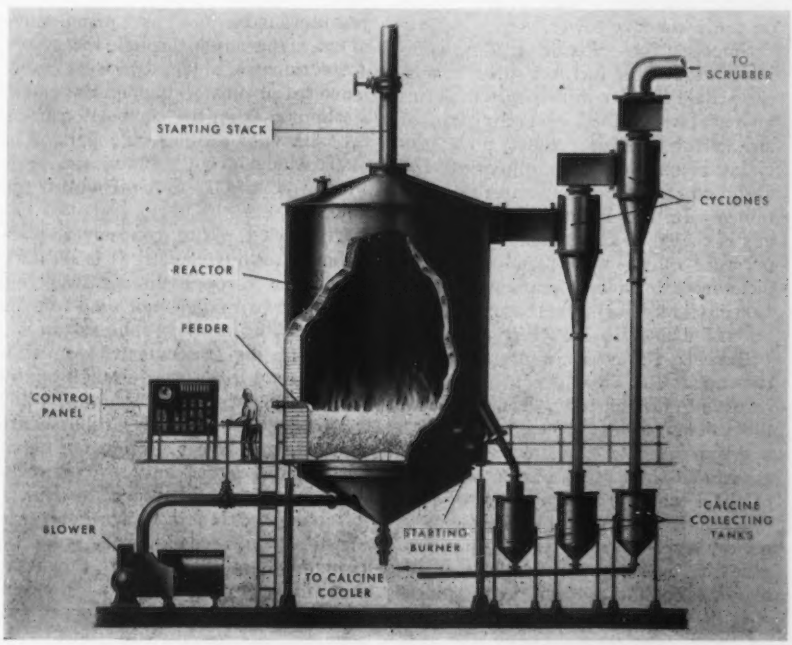


Figure 4—General Arrangement of Dorrco FluoSolids System for SO_2 Production

bend having a water seal at the top. Sufficient water is supplied to maintain a film over the vertical section, with the water thus supplied maintaining an overflow in the pond below. Both the old type pond coolers and the Jenssen coolers are equipped with water seals on the submerged headers, and these can take care of any small leaks in the piping or help take care of sulfuric acid accumulations.

The spray type cooler is essentially two scrubbing towers in tandem. The gas from the combustion chamber enters at the top of the first and smaller tower where it is hit by a spray of water, previously warmed in the second tower. This spray immediately cools the gas to below 70 degrees Centigrade, and washes out any sulfur or sulfate. The wash water accumulates in the bottom of the tower, from which it overflows through a seal box to the sewer. A visual inspection of this overflow will show if there is any sulfur sublimation, as the minute sulfur particles give it a somewhat milky appearance. A chemical test will show if a given type of burner operation is producing any amount of sulfur trioxide. The gas from this primary tower goes through a short stainless steel pipe to the second, larger tower, entering at the bottom. This is a packed tower, with the spray at the top, and the gas exit also at the top. The spray water from this tower is also collected at a seal box where make-up fresh water is added. Part of this liquor is pumped to the spray at the top of the primary tower, the balance going to the heat exchanger for cooling and thence back to the sprays on the secondary tower.

Since sulfur trioxide readily combines with water to form sulfuric acid, the primary tower in this system forms an excellent method of getting rid of any sulfur trioxide present, no appreciable amount of sulfur dioxide being absorbed at the temperature maintained. In the secondary tower, the gas is cooled to approximately the temperature of the water, and the water picks up a considerable amount of sulfur dioxide. For this reason it must be cooled and used over again.

Between the cooler and the absorption apparatus there are usually more recording instruments. A measure of the vacuum is often desired as, with a given speed on the gas fan, it constitutes an indication of the tightness of the system, or the presence of sublimed sulfur. A recording thermometer on the cooled gas is usually used to give the operator a guide in controlling his cooling system. Also, unless it is desired to control the back draft on the burner automatically, the cold gas line is the ideal spot to take a sample for the gas analyzer, as the instrument is much less troublesome when operating on cold gas than on the hot gas immediately after the combustion chamber.

Other Sources of Sulfur

So far we have considered only systems making use of elemental sulfur. With the advent of the Frasch process and the subsequent development of the mines along the Texas and Louisiana Gulf Coast using this process, other producers of sulfur were largely squeezed out, and those mines took over seventy-five percent of the world market. With the rapid growth of the heavy chemical industry, this supply has now become inadequate, and attention is turning more and more to other sources, the most plentiful of which seem to be the iron sulfides.

The formula for iron pyrites, FeS_2, would indicate a content of 53.46 percent sulfur and 46.53 percent iron. The material most readily available is in the form of mining concentrate and will run between 47 and 51 percent sulfur and somewhat finer than 60 mesh. This type of material has been used in the Nichols Freeman flash roaster installation at the St. Lawrence Paper Mills Company at Three Rivers, Quebec, since 1932.

Nichols Freeman Flash Roaster

This plant consists of a pyrite hopper and feeder, air swept ball-mill, brick lined cylindrical combustion chamber which is 11 feet in inside diameter, dust settling chamber, waste heat boiler, recirculating fan, spray cooler, together with the conventional Jenssen gas fan used as a prime mover to draw the gases through the system. There is also a pan conveyor to remove to an outside hopper the calcine discharged from the combustion chamber and dust settling chambers. This plant was laid out to burn the pyrite equivalent of 12 tons of sulfur per day.

The dried pyrite concentrate (less than one percent moisture) is fed from the hopper through the air swept ball mill. The ball mill is not used to grind the ore but merely to break up any lumps of the concentrate formed in storage, and to insure thorough mixing of the concentrate with the air, which carries it through the burner nozzle into the top of the combustion chamber. The gas stream moves directly downward as a distributed shower of burning particles, meeting the incoming draft of secondary air from the bottom. Here the most of the heavy impurities drop out through the outlet of the cone into the hopper and conveyor. The gases, with some of the finer material in suspension, are drawn out of the top of the combustion chamber, into the dust chamber (at which point more calcine is discharged to the hopper) and into the waste heat boiler where they are cooled rapidly to below 400 degrees Centigrade. Part of this partially cooled gas is drawn on to the scrubbing tower, and part is pumped back to join the incoming stream of air and air-borne pyrites. This return of a portion of the partially cooled gases serves a dual purpose. While it is advisable to have a temperature in the vicinity of 1000 degrees Centigrade in the combustion chamber to inhibit the formation of the trioxide, the temperature can be regulated to keep from going much higher by introducing the necessary amount of partially cooled gas. It also serves to increase the percentage of sulfur dioxide in the gas going to the absorption towers, increasing the efficiency there. The final cooling is taken care of in a pair of scrubbing towers, operating about the same as when used for cooling gas which is made by burning elemental sulfur.

The Dorr Fluosolids Roaster

The formula for pyrrhotite, FeS, would indicate a content of 36.45 percent sulfur, and some of the deposits show pyrrhotite containing 33 to 35 percent. There are a couple of large deposits of this material in Maine, and a number of smaller ones. The larger one, the so-called Katahdin deposit, has had test drilling which would indicate enough of the ore to take care of the sulfur requirements for the state for the next 125 years. It has been suggested that the Dorr Company's FluoSolids roaster would take care of this type of ore, and one is being installed at a nearby plant, but is scheduled to use pyrites as mining concentrates from Vermont.

In the FluoSolids roaster, see *Figure 4*, we again have a large, cylindrical, vertical, brick-lined combustion chamber, equipped with a perforated bottom plate, starting burner, slurry feeder, blower, cyclones, water spray, waste heat boiler, scrubbing towers, and fan.

In operating this burner, the material, 14 mesh or finer, is fed as a slurry with a worm feeder at a height of five feet above the perforated plate. The blower keeps an air pressure of four or five pounds in the chamber below the plate, and, with this air coming up through the material, it acts as a fluid, each particle being individually suspended in the air and burning in the bed. On the opposite side of the chamber from the feeder and at the same height, a discharge pipe is provided through which about 75 percent of the resulting sinter is discharged to

a quench tank. A water spray is provided at the top of the combustion chamber which is controlled by a pyrometer in the head of the chamber to keep the temperature from going much over 1000 degrees Centigrade. The gas is drawn off at the top, passes through one or more cyclones to take out the rest of the dust and thence to the waste heat boiler and scrubbing towers.

While about 2.3 pounds of steam can be produced for every pound of sulfur burned, about 1.5 pounds of steam can be produced per pound of dry pyrite. Monthly averages reported from the St. Lawrence plant have ranged from 1.34 to 1.68.

Sulfite Acid Preparation

Donald Griffee[1]

Graduated from the University of Maine in 1942 with a B.S. in Mechanical Engineering. Served with the U.S. Air Force from June 1942 to March 1946 with the Air Technical Service Command at Wright Field, Dayton, Ohio. Hired by the Eastern Corp. in April, 1946 as a member of the engineering department. In April 1948 transferred to the Pulp Mill and spent a year at Eastern's Katahdin Mill at Lincoln, Maine as assistant Pulp Mill Superintendent. Returned to Brewer in 1949 as Pulp Mill Superintendent at Eastern Corp.'s South Brewer Mill.

Raw Materials of Acid Making

Of the raw materials used in acid making for the sulfite pulping process, the main item is sulfur which occurs in elemental form in Texas and Louisiana. It also occurs in the form of iron pyrites all over the world. There are some sulfur deposits in the pure form, in Sicily and Japan.

In addition to sulfur we have various raw materials which serve as the basis of the bi-sulfite in the acid. The calcium base acid utilizes limestone, which is nearly pure calcium carbonate, and is generally made in the tower system. Dolomite, a mixture of calcium and magnesium carbonates, is used to make acid principally in the Barker, or milk of lime, towers. The soluble bases, magnesia and ammonia, are readily formed in the Barker tower or in the case of ammonia in a packed tower.

The magnesium base system uses either caustic magnesia or magnesite, which is native magnesium carbonate. There are some natural deposits of the latter on the west coast. Magnesium oxide can be made from sea water by precipitating magnesium hydroxide with slaked lime, and washing and heating it to produce the light, fluffy oxide.

The ammonia base system makes use of anhydrous ammonia which is practically 100 per cent liquid ammonia. It may be obtained as a by-product of coke manufacture or it may be synthesized by the Haber process.

Chemistry of Acid Making

Since the preparation of sulfur dioxide has been previously discussed we will now take up the chemistry of the various bases. We have three main bases namely calcium, magnesium, and ammonia. I am not going into the sodium base because it is not commonly used.

The calcium base is the most widely used in the sulfite industry in the United States and Canada and, I think, world wide. In the tower system, or Jenssen tower, where we use limestone we have the following reaction taking place:

$$CaCO_3 + SO_2 + H_2O \rightarrow CaSO_3 + H_2O + CO_2 \quad (1)$$

That is the first reaction that takes place in a Jenssen tower where the water is cascaded down over limestone set on a rack in the tower. We will explain the operation of towers later on in more detail. In a milk of lime system we have the following reaction:

$$CaO + SO_2 + H_2O \rightarrow CaSO_3 + H_2O \quad (1a)$$

You will note that calcium sulfite is formed in both cases. Also in the milk of lime system which I will explain in more detail later, there is some magnesium oxide present and the reaction of that will be described for the magnesium base system.

Now, calcium sulfite is very insoluble in water. That is what we call the mono-sulfite. If we had insufficient sulfur dioxide in the towers, that amount of sulfite would plug things up very effectively. That has happened in operations where we have run into trouble with burners and our concentration of sulfur dioxide has decreased. But with an excess of sulfur dioxide and water, the calcium sulfite becomes calcium bisulfite according to the following reaction:

$$CaSO_3 + H_2O + SO_2 \rightarrow CA\ (HSO_3)_2 \quad (2)$$

That is the next reaction that takes place in the acid tower whether it be the tower system or the milk of lime system. It is this combined sulfur dioxide, calcium bisulfite, that is the base of the sulfite acid. All of the sulfur dioxide was not used up to form the combined. There is still an excess of sulfur dioxide in the absorption tower and that combines with water to form the free sulfur dioxide or sulfurous acid according to the following reactions:

$$SO_2 + H_2O \rightarrow H_2SO_3 \quad (3)$$

With the magnesium base, the reactions are very similar. The purpose of the magnesium base in the sulfite process is to allow recovery of the chemicals used in the manufacture of the acid. Theoretically, the process for recovering the chemicals is not too complicated. It is done by burning the waste liquor which produces a fly ash of magnesium oxide and sulfur dioxide in the flue gas. The sulfur dioxide is taken from the flue gas, cooled, and absorbed in the acid towers and the fly ash or magnesium oxide is collected, made into a sludge, and used as a base in the towers. I understand that quite a lot of trouble was encountered at first with insoluble magnesium monosulfite. The original plans of operation were to put all of the magnesium oxide slurry into one tower. It was soon discovered that an insufficient excess of sulfur dioxide was present there to form bisulfite and the system plugged.

For magnesium base operation with chemical recovery, pilot plant figures indicated something like 15 pounds of magnesium oxide consumption per ton of pulp produced and some 25 pounds of sulfur per ton of pulp produced. This was very attractive economically since in most sulfite pulp mills that do

[1] Pulp Mill Superintendent, Eastern Corp., Brewer, Maine.

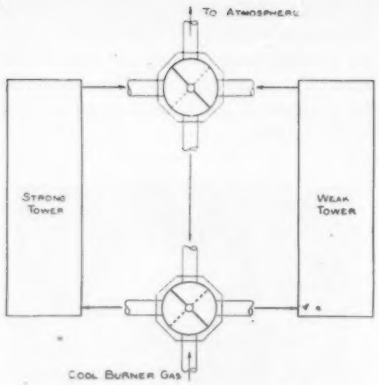


Figure 1—Diagram of Jenssen Two-Tower System

not have chemical recovery, the consumption of sulfur is between 200 and 300 pounds of sulfur per ton of pulp produced, while the base materials run 100 to 200 pounds per ton. Unfortunately, the operators have not been able to get their chemical recovery as high as the pilot plan indicated. About the best they have been able to do is 49 pounds of magnesium oxide per ton of pulp and about 103 pounds of sulfur per ton of pulp. The savings there are not so great and with the capital expenditure necessary for all the equipment in the magnesium base process it will take them considerably longer to pay off their investment.

Chemical recovery with the ammonia base process is quite dubious. I understand that a Swedish gentleman, now in this country, has a scheme for chemical recovery with ammonia base acid. I do not know what it is. Of course, you cannot burn ammonia base waste liquor and recover ammonia because it breaks down into hydrogen and nitrogen. Sulfur recovery is possible, although the economics involved are somewhat complex. The raw material cost of the ammonia base is somewhat higher than either lime or magnesium. There are some advantages that offset this. For instance, we feel that the pulp quality is somewhat better, the pulp bleaches easier, and you should get higher porduction of pulp with existing digesting equipment.

The chemistry of acid making with ammonia base is very simple as far as theory is concerned. I guess there are some rather complex compounds that are formed in the acid making process that nobody has been able to establish definitely, but in theory we have the following reaction:

$$NH_4OH + SO_2 + H_2O \rightarrow NH_4HSO_3 + H_2O. \quad (4)$$

There is no monosulfite formed nor are there any insoluble materials in the system to worry about. The combined sulfur dioxide, ammonium bisulfite, is formed almost instantly. The excess sulfur dioxide forms the free sulfur dioxide with water the same as with the other bases, equation (3).

That covers pretty much the chemistry involved for the acid making process in the sulfite pulp industry.

The Tower System

We will go on now and talk about the absorption towers, which vary considerably from mill to mill. *Figure 1* shows a schematic diagram of a Jenssen two-tower system. With the tower system there is usually a strong tower and a weak tower. Both towers are packed with limestone on a grate which is a perforated plate of some kind. The tower is usually constructed of reinforced concrete with an acid proof lining of brick along with litharge and glycerine joint material. Water is fed to the top of the weak tower and down over the limestone. Weak sulfur dioxide gas from the top of the strong tower goes into the bottom of the weak tower, and up through the water coming down over the limestone. I believe, generally, that in the weak tower, you would not form much free sulfurous acid. Probably the acid would be mostly bisulfite portions. The sulfur dioxide comes from the cooler into the bottom of the strong tower and passes up through the grate. There is usually a cribwork of wood timbers to give more absorption surface. Liquid from the weak tower is fed to the top of the strong tower so that the flow is counter-current through the two towers.

One of the disadvantages of the tower system is lack of control over the base material. It is packed in the tower and, in the summertime when the water temperature is higher, limestone dissolves more readily. Attempts have been made to go into the weak tower and take out some limestone, but this is an awkward process and there really is no control of combined sulfur dioxide, unless there is temperature control of the water to the absorption tower.

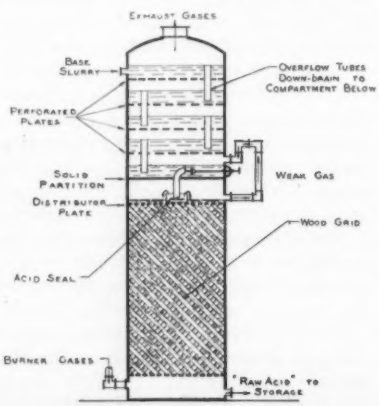


Figure 2—Elements of Barker Acid Tower

There are modifications of the basic tower system. Some mills have three or four towers in succession, but they operate about the same as the two tower system. One tower might be taken out of service completely for packing.

The Milk of Lime System

The milk of lime system, *Figure 2*, is a combination of an absorption tower and a series of suspension tanks. It has a series of perforated plates, usually three or four, depending on the size of the tower. Those plates are perforated with numerous small holes. The tower might be eight or nine feet in diameter and the holes in the plates might be one-half or three-fourths of an inch in diameter with as many as 200 of them in each plate. The plates are usually of heavy lead. The tower itself is steel, usually, with an acid proof lining of brick joined with litharge and glycerine.

Usually the lime is slaked in a tank. The lime is weighed, turned into a tank, and agitated for a length of time sufficient to slake the lime. It flows through a perforated plate in the bottom of the slaking tank and runs into a storage tank where it is diluted to a constant concentration. Lime is slaked on a batch basis and a supply is kept ahead at all times.

The lime water from the storage tank is pumped up to the top of the Barker tower, or milk of lime tower, and from there it flows in onto the top plate by gravity. The tower is under a vacuum which is approximately eight or nine inches of mercury. That is in contrast to the tower system which is usually operated under a pressure of about four and one-half pounds per square inch. In the tower system, the sulfur dioxide is forced through the tower. In the milk of lime system, the gas is pulled through by means of the vacuum.

The vacuum keeps the lime water on the top plate at a certain level, usually two feet deep. There is an overflow pipe from the top plate extending below the liquid level on the second plate. The lime water on the top plate goes down the overflow pipe to the second plate where it is held up by the vacuum. The second plate, or floor, is also perforated and has an overflow pipe. The liquid flows down over four or five of these floors to the last one which is about middle way up the tower.

Under the last perforated plate there is usually a lot of cribwork which is often nothing more than pieces of yel-

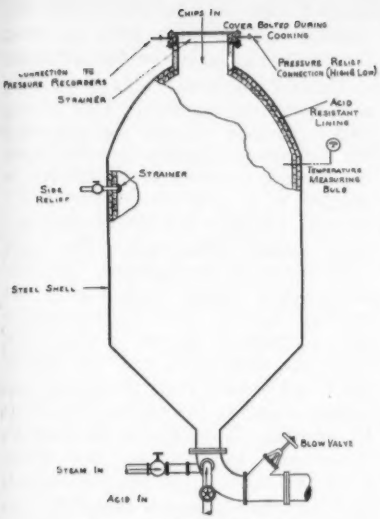


Figure 3—Sulfite Digester

low pine that are four to six inches square, piled across one another. The purpose of the cribwork is to spread the liquid over a larger area to get better absorption. The overflow from the last floor goes outside the tower, has a long, vertical loop, and comes back in to discharge down onto the cribwork. The purpose of that is to have a liquid seal for the tower. The plates being perforated, some of the lime water goes through these perforations and down that way. However, the majority portion goes through the overflow pipe, through the seal, back again, and down over the cribwork.

The sulfur dioxide comes in through a pipe at the bottom of the tower and is pulled through by vacuum. The gas bubbles up through the floors where the sulfur dioxide reacts to form "raw acid," so called, and the inert portions pass through the vacuum pump to the atmosphere.

One of the constant headaches of the milk of lime system is the plugging of the top floor with lime. Depending on the quality of the lime, it might be necessary to unplug that floor from once a day to once every two hours. There is not enough sulfur dioxide concentration by the time it gets up to the top to keep the floor clean. Some of the old time operators in the acid plants pride themselves on the fact that they can keep the top plate clear. They do it by pulling enough sulfur dioxide to keep it cut away. You could not stay in the room without a gas mask. Those fellows can sit there and take it. Of course, it is a waste of sulfur.

The reactions which were discussed earlier take place pretty much on these various floors. The reaction at the top is the formation of the monosulfite and rapidly goes from there to form the calcium bisulfite. I would say the free portions are probably formed as the liquid comes down through the cribwork where the gas is fairly strong. The combined is pretty much formed before the liquid gets down to the cribwork.

The weak acid is pumped from the bottom of the milk of lime tower and goes from there on to the recovery system, or the storage tanks, whatever the arrangement may be. We will briefly discuss the recovery system later on.

Paulson Acid Towers

The Kimberly Clark, or Paulson, acid towers are a type of milk of lime system that has been somewhat refined. The basic operation is the same. This system makes use of bubble caps on top of the plates which tend to confine the gas somewhat and it is claimed that somewhat better adsorption is obtained than with a perforated plate. They usually consist of two towers so that one or the other can be cut into the system in a manner similar to the tower system. When the operators find plugging at the top they do not have to shut down for cleaning. They can just change over to the other tower.

This business of shutting down the acid plant to clean the top plates is a constant source of trouble in any milk of lime system. There is usually a mercury manometer located at a place where the operator can easily see it. When he sees the vacuum start to increase he knows that the top plate is plugged and he must shut down to clean it out. Each shutdown of an acid plant results in considerable dilution of acid, because to start up, it is necessary to fill the tower before putting the gas through. This water and lime water must necessarily go into the storage tanks and its volume of liquid has a tendency to weaken the acid and cause variations in the cooking. So it is very desirable, once an acid plant is started up, to keep it running.

The Effect of Water Temperature

One thing that is of prime importance with all the bases, and in all the absorption towers, is the temperature of the water used to make the acid. Sulfur dioxide can be absorbed in water much more readily when the water is cold. In the summertime, even in Maine, it does get warm enough so that the water temperature goes high enough to bother the acid making operations. There have been several things done to correct this. Some people dig artesian wells to get cold well water to make their acid. Others have gone to cooling the water used to make acid by refrigeration. We have a Graham steam jet refrigeration machine at the Eastern Corp. which cools our water in the summertime by 10 to 15 degrees Fahrenheit. Generally speaking, the water going into the acid tower does not have to be much warmer than 50 degrees Fahrenheit.

In the tower system, this high water temperature causes the limestone to dissolve much more readily than does cold water. That is where this business of not being able to control the

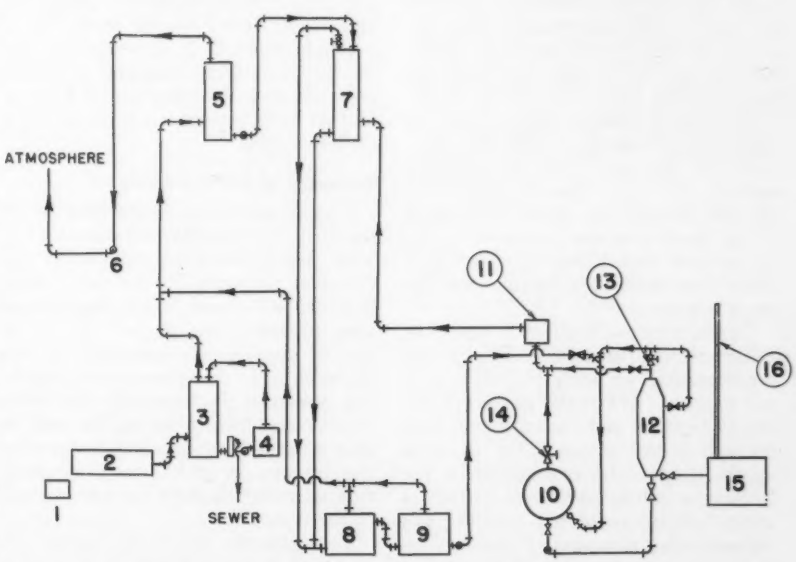


Figure 4—Acid Making and Sulfur Dioxide Recovery System. No. 1, Sulfur Melter; 2, Sulfur Melter and Combustion Chamber; 3, Spray Cooling Tower; 4, Spiral Cooler for Cooling Tower Spray; 5, Barker Acid Tower; 6, Vacuum Pump; 7, Relief Tower; 8, Constant Level Acid Storage Tank; 9, Acid Storage; 10, Hot Acid Accumulator; 11, Low Pressure Relief Gas Cooler; 12, Digester; 13, Digester Pressure Control Valve; 15, Blowpit; 16, Blow Stack.

combined comes in. The water gets warmer, the limestone dissolves much more readily, the sulfur dioxide does not absorb as well in warmer water, and a high combined sulfur dioxide results in the acid. It is expensive in the first place and a desired high strength of cooking acid cannot be obtained.

Control of Acid Making

Let us discuss some of the control methods used in acid manufacture. Of course, weighing the raw material is fundamental. To keep an accurate record of all the materials that go into the process, the sulfur and the lime or magnesium must be weighed. Ammonia is in liquid form so it is measured by volume. We buy anhydrous ammonia which is almost 100 per cent ammonia and dilute it to around 30 per cent ammonia. Any concentration could be used, but it is better not to go much over 30 per cent because storage at atmospheric pressure at higher concentrations might cause a loss of some of the ammonia due to elevated temperature in the summertime. In the wintertime, of course, it does not make too much difference.

One of the most important controls in the acid making process is the control of the sulfur dioxide concentration in the gas coming from the burner. One rather complicated instrument, usually manufactured by Leeds and Northrop Co., measures the concentration of sulfur dioxide in the gas coming from the burner. Fundamentally, air is about 21 per cent oxygen so obviously we cannot get the sulfur dioxide concentrations from the air and sulfur any higher than 21 per cent. One control which is manufactured by Leeds and Northrop Co. measures this gas concentration in the cooled gas. It takes a sample from the pipe coming from the burner and measures the concentrations of sulfur dioxide in that gas. This information is relayed through an electrical impulse to an electric motor operated valve, in our case controlling the steam turbines that pump the sulfur into the spray burner.

Our instrument happens to be set at 19 per cent sulfur dioxide. That is the concentration we wish to run day in and day out. When the gas drops below 19 per cent and the impulse is sent through to this motor valve, it opens up the steam valve and speeds up the turbine a little so more sulfur is pumped into the burner and the gas concentration increases. If the concentration happens to rise above 19, the instrument will send an impulse to that motor valve and shut it off a little and that, in turn, decreases the amount of sulfur pumped and hence the concentration of sulfur dioxide in the burner gas. It is a very delicate instrument and requires a good deal of maintenance to keep it operating properly.

There are several things that affect the gas control. One is the relief from the digester room. If much relief from the digester room is fed into the basic tower in any way, that will affect the concentration of gas coming from the sulfur burner. In other words, the absorption tower can only take so many volumes of gas. There is only room for so much gas through the tower under the operating conditions. If some gas comes in surges from another source, then it will either tend to restrict or in case of heavy quantities coming in, block off the gas coming from your burner, and that, of course, will cause the concentrations to go up. Due to the time lag of the gas controller, (it takes time for it to measure the gas concentration and send this electric impulse to the motor valve) we sometimes get a situation where we "pull cold sulfur." In other words, we pull gaseous sulfur through from the burner and it condenses out in the cooler portions of the system and has a tendency to plug them up.

There is another control that is used somewhat, especially in the milk of lime system. It is an electric control of lime water addition. It is nothing more or less than electric contacts that are put in somewhere along the system of plates. As the solution becomes more acid, its electrical conductivity becomes higher. A small current passing through one side of this control to the other side of the control will operate a valve controlling the amount of lime water added in the tower. It is a simple control. It does not prevent the top plate from plugging up, however; there is no control that I know of that will prevent that in the milk of lime system.

Recovery of Sulfur Dioxide

I would like to go into a little bit of the recovery of sulfur dioxide as such. Now this is not what you would call chemical recovery in the same sense that we talk about in the magnesium base process. But it is recovery in that a considerable quantity of the sulfur dioxide that goes into the cooking operation is recovered. In order to describe this it would be well to give a brief idea of what happens in the digester during the cooking operation by going through the actual cycle of the cook.

Basically, the shape of a sulfite digester is shown in *Figure 3*. The wood chips are inserted from the top and the digester is filled up with wood. Once that is done and the cover is bolted down, the cooking acid is pumped into the bottom. Now this cooking acid is quite different from the acid we make in the Barker tower or the tower system. This is a strong acid compared to that. This strong acid is pumped into the digester until the digester is full and then the pump is stopped. Usually the digester is pumped to a pressure of 90 or 100 pounds. We have side relief strainers, a side relief outlet, and at the top a relief outlet of the digester. This, incidentally, is typical of the system that we have at the Eastern Corp. and a flow diagram is given in *Figure 4*. Once the digester is full, the acid is circulated around from the strong acid storage vessel to the digester for about 15 minutes. That gives the acid an opportunity to penetrate the wood. Once that is done, the pump is shut off and then the valves are closed. We introduce the steam into the bottom of the digester and the cooking begins. During the cook it is necessary to relieve excess gas from the digesters to hold constant pressure. The gas coming from the digester is almost 100 per cent sulfur dioxide, and goes back to the strong acid storage, or accumulator. This is the main fortification of the acid that takes place.

The accumulator is kept under a pressure of about 45 pounds and the temperature might be 150 degrees Fahrenheit. A slight pressure or temperature change can change the concentrations of the acid considerably so it is quite important to control both in the accumulator.

In order to control the pressure, we have to relieve the excess gas off this vessel and, of course, that is hot, 150 degrees Fahrenheit. We certainly do not want that hot gas going into the absorption system after going to a lot of trouble to keep the system cool. So we have to put it through a cooler, called our low pressure relief cooler. There are several types suitable for this purpose. We use a spiral, steel type of heat exchanger made by the Rosenblad Corporation.

We do not want this cooled gas to go directly to the milk of lime tower, or the Jenssen tower, because of the surges and trouble it will cause with the sulfur dioxide controller. We have another absorption tower in the acid plant which we call the relief tower. It is a simple tower built of steel and is lined with acid proof brick. Our low pressure relief line feeding this tower has a pressure running from 5 to 35 pounds. This relief goes into the absorption tower which is filled with cribwork similar to that in the bottom portion of the barker tower. The acid from our barker tower is pumped to the top of the relief tower. This tower is usually kept under slight pres-

sure, somewhere under ten pounds, in order to absorb the sulfur dioxide more readily. Of course, the flow of gas from the cooler does not come steadily. It surges more or less, depending on how the digesters are cooking. Then the acid from the relief tower goes out to the storage tanks where we keep a body of acid on hand at all times.

Now we also have a relief from the top of this tower. The tower is maintained at ten pounds pressure and relief from the top of the tower goes out to our acid storage tanks. We have three hard pine acid tanks. They are probably 25 to 26 feet in diameter and about 15 feet high. The acid relief from the relief tower goes into the first of the tanks which is called the constant level tank. That tank overflows into the other two tanks. The other two tanks are connected at the bottom so their level is the same all the time. The constant level tank always has a body of acid up to the over flow pipe which is nearly two-thirds of the way up the side of the tank. There is some more build up of acid strength in that tank. It is just a question of trying to pick up all the loose ends around the acid plant and at the same time try to keep the surges that come from the cooking process away from the sulfur dioxide control.

There is always relief of excess gas from somewhere. Relief from the acid storage tanks is sometimes brought into another small absorption tower. Sometimes it is fed back into the first absorption tower. With all the attempts at recovery you still get the last dregs of gas coming out of the acid storage tanks.

The acid from the storage tanks is pumped into the accumulator. Usually it is pumped into the top of what we call the drop leg. Cold acid at 70 or 80 degrees Fahrenheit is pumped back from the storage tanks into the accumulator where we store the acid in preparation for cooking. The hot relief from the digester and the cold acid come together in the drop leg pipe coming down to the accumulator and this relief helps to heat the acid up to a temperature of 150 degrees Fahrenheit.

Acid Concentrations

Now let me give you a rough idea of the acid concentrations at various points in the system. In the absorption tower the concentration might be about two per cent free sulfur dioxide and have a combined of about 1.9 per cent. That will be a total there of 3.9 per cent. It will, of course, very. However, the acid maker conducts hourly tests to keep it uniform as possible.

Of course, the acid from that tower goes into the relief tower and out to the storage tanks. Coming into the storage tanks, there might be a free of four per cent, a combined of 1.5 and, therefore, a total there of 5.5.

Now in the accumulator the combined has dropped off. It started out at 1.9 in the tower and went down to 1.5 in the storage tanks. As the acid is fortified there is a tendency to reduce the combined portion of the acid because of dilution and increase the free portions. So it is necessary to start out with a higher combined figure than is desirable to cook with in order to compensate for that. In the accumulator, the increase of the free portion is from four to six and one-half per cent. The combined would be about 1.25 per cent and the total around 7.75 per cent. That is the final cooking acid that goes into the digester and does the work.

Sulphite Pulp Acid Making Systems

Oscar E. Anderson[1]

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Introduction

The American chemist Tilghman, the Swedish chemist Ekman, the German chemist Mitcherlich, and the Austrians Ritter and Kellner all had a hand in the early developments of the sulphite pulping process. In various ways they used sulfur dioxide combined with various bases. It was soon found that a base was necessary to combine with the wood acids formed during the cooking in order to avoid obtaining a dark colored pulp.

It is the function of the acid plant to combine the sulphur dioxide obtained from various sources, with a suitable base forming "raw acid." This raw acid in turn, is mixed with the sulphur dioxide which is obtained from the digester relief liquor and relief gases forming "cooking acid." A previous lecture has dealt with the preparation of the sulphur dioxide, and a future article will deal with recovery systems and cooking. This paper, therefore, begins with the cooled sulphur dioxide gas as delivered to the "towers" and ends with the delivery of the raw acid to the storage tank, where the change over to cooking acid begins. It is, therefore, presumed that you are reasonably well acquainted with the melting and burning of sulphur and the cooling of the sulphur dioxide gas.

Bases

The following bases or combinations of bases may be used:

(1) High Calcium
(2) Calcium and Magnesium (Dolomite)
(3) High Magnesium
(4) Soda
(5) Ammonia

The high calcium base is generally used in the form of limestone in packed towers. The combination of calcium and magnesium is commonly used in the milk of lime system although with proper design allowing for ample tower capacity it may be used in a limestone tower system. While in dolomite calcium and magnesium carbonates exist in approximately equal quantities, and are commonly used in

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TABLE I

Form	Calcium or Magnesium Limestone or Lime	Sodium Soda Ash	Ammonia Anhydrous Ammonia
Cost per ton Base	$5.00	$35	$70
Consumption #/ton (no recovery)	300	300	100
Cost per ton Pulp	$.75	$5.25	$3.50
BTU Value of Solids	8300	....	9000
% Ash	14.6	....	1.1

milk of lime systems, there are many cases where the limestone used is not dolomite and may contain substantially less magnesium carbonate than calcium carbonate and is often found in limestone tower systems. The limestone tower should preferably be designed for a given kind of limestone since a greater height of tower is required as the percentage of magnesium carbonate increases.

The high magnesium base is being used in connection with the recovery of both the base and the sulphur from the sulphite waste liquor and represents a special application.

Because of the great solubility of both sodium and ammonium bisulphites in water the use of these bases represents special applications and may be used by modification of either the limetone or milk of lime systems in which considerably smaller equipment may be used.

Cost

The cost of the different bases varies widely from year to year and in different localities. Proximity to quarries or manufacturing plants has, obviously, a great bearing on delivered costs of the various bases. *Table 1* will give an approximate idea of how these costs may run.

It will be noted that while the difference in cost of bases is relatively large percentagewise, it is actually not a large part of the total cost of sulphite pulp. It is becoming increasingly apparent that other advantages may outweigh the difference in cost of the bases.

Advantages and Disadvantages

In order to understand the relative merits of these bases, the solubility of various compounds of these bases in cold water is presented in *Table II*.

As can be noted from the table it would be expected that there would be practically no liming or scaling problems with the ammonia or sodium bases but that they would increase with magnesium and become quite severe with calcium bases. Because most calcium salts have an inverted solubility curve, the calcium base constitutes an ever present source of trouble due to deposits of calcium sulphite and calcium sulphate particularly.

From the standpoint of materials handling, the ammonia base may have a distinct advantage with the proper equipment. The soda base may be integrated with bleach plant or kraft mill operations and may fit in very nicely from a materials handling viewpoint.

While much work remains to be done on the matter of recovery of chemicals from the sulphite waste liquor, indications are that the advantages lie in reverse order to that given in Table II. It is obvious that scaling problems in evaporation and burning of the waste liquor, as well as recovery of sulphur and the base, is much more difficult with the calcium base that, for instance, in the case of the ammonia base.

Table III shows a typical high calcium limestone analysis which we use at our plant.

You will note that that amount of magnesium oxide is very small and over the years this analysis has been very satisfactory for us. In many cases the amount of impurity is much greater than this and requires larger settling tanks and more frequent washing out of these settling tanks.

Sometimes changes are made in the cooking or in the kind of wood used which necessitates changes in the acid making process. Flexibility in obtaining the necessary composition of the acid varies with the different systems. *Table IV* shows a typical change in acid found necessary as a result of chip packing in the digester. Attention is called to the fact that before chip packing the acid plant was supplying a percent combined sulphur dioxide, SO_2, of 1.59 while after chip packing it was necessary to increase this to 1.90.

TABLE II

	Carbonate	Hydrate	Sulphite	Sulphate
Calcium	.0013	.17	.0043	.179
Magnesium	.0106	.0009	.62	26.9
Sodium	21.5	42	13.9	5.02
Ammonium	100	103	100	71

(NH_3 in H_2O)

CA SO_3 .0043 18° C.
CA SO_3 .0027 90° C.

Chemistry of Acid Making

The following reactions may be involved in acid making.

The sulphur is burned to the dioxide, $S + O_2 = SO_2$, following which it is dissolved in water,

$$SO_2 + H_2O = H_2SO_3.$$

TABLE III

Silica & Impurities	.77
Iron & Aluminum Oxides	.42
Calcium Oxide	53.38
Magnesium Oxide	1.78
Ignition Loss	43.63

If a milk of lime system is used the calcium oxide is slaked

$$CaO + H_2O = Ca(OH)_2$$

The calcium hydroxide reacts with the sulphurous acid to form calcium monosulphite

$$Ca(OH)_2 + H_2SO_3 = CaSO_3 + 2H_2O$$

With the excess of sulphurous acid, the bisulphite is formed.

$$Ca(OH)_2 + 2H_2SO_3 = Ca(HSO_3)_2 + 2H_2O$$

In the tower system using calcium carbonate the following reaction takes place:

$$CaCO_3 + H_2SO_3 = CaSO_3 + Co_2 + H_2O$$

In the presence of an excess of the sulphurous acid, the bisulphite is formed

$$CaCO_3 + 2H_2SO_3 = Ca(HSO_3)_2 + CO_2 + H_2O$$

or,

$$CaSO_3 + H_2SO_3 = Ca(HSO_3)_2.$$

Reactions with magnesium base are similar to those given for calcium base. The soda base beginning with soda ash would be

$$Na_2CO_3 + H_2SO_3 = Na_2SO_3 + CO_2 + H_2O$$

$$Na_2CO_3 + 2H_2SO_3 = 2NaHSO_3 + CO_2 + H_2O$$

and for ammonia

$$NH_4OH + H_2SO_3 = NH_4HSO_3 + H_2O$$

TABLE IV

	Before Packing	After Packing
Lbs. A.D. Pulp/cu. ft.	4.50	6.20
Lbs. Steam/ton	4450	2880
Lbs. Sulphur/ton	270	189
Gal. Acid/ton	2350	1610
Cooking Acid Total SO_2	5.38	7.18
Cooking Acid Comb. SO_2	1.09	1.34
Raw Acid Total SO_2	4.39	4.65
Raw Acid Comb. SO_2	1.59	1.90

We use the usual mill definitions for "free" and "combined" SO_2. The "combined" is the amount of SO_2 necessary to combine to form the monosulphite, in the case of a calcium

base $CaSO_3$, or one-half that required for the bisulphite. The "free" is the difference between the total SO_2 and the combined SO_2.

Types of Acid Making Systems

There are two general types of acid making systems, the limestone system and the milk of lime system. The older limestone systems used tall towers, the Mitcherlich towers being as much as 100 to 115 feet high and relatively small in diameter. The more modern towers, the Jenssen system, have larger diameter and shorter towers and are generally built of concrete with an acid resisting lining. Our towers happen to be built of steel and, of course, have an acid proof lining. These are the only steel Jenssen towers that have come to my attention. This system is generally operated under a slight pressure as the burner gas is supplied through a low pressure fan or blower.

In the limestone system the base is supplied in the form of limestone, while in the milk of lime system a slurry of the base is used. The more common Barker system is a milk of lime system using a heavy absorption tower with an acid proof lining. It is operated under reduced pressure and the burner gas is drawn through with a vacuum pump. In modern practice a pressure system is also used for milk of lime. With the advent of soda, ammonia, and magnesium bases special adaptations of both systems may be used.

Jenssen System

A two tower system is most commonly used as shown in *Figure 1.*

Three or four tower systems may be used, depending upon capacity required. The gas enters a four-way valve at the bottom of one tower, passes upward through this tower and is then taken through a lead pipe to the base of the other tower. These towers are interchangeable by means of the four way valve for handling the gas and a six way valve for handling the water and acid. The tower where the strong gas first enters is the "strong" tower, and the other becomes the "weak" tower. The water is pumped into the top of the weak tower, flows down over the limestone counter-current to the gas. From the bottom of the weak tower it passes through the six way valve as weak acid and is pumped to the top of the strong tower, emerging from the strong tower as "strong" acid, going to the acid settling tank and then to the storage tank.

Ordinarily about 90 percent of the gas is absorbed in the first tower. The loss from the second or weak tower should, therefore, not be over one or two percent. This permits filling of the

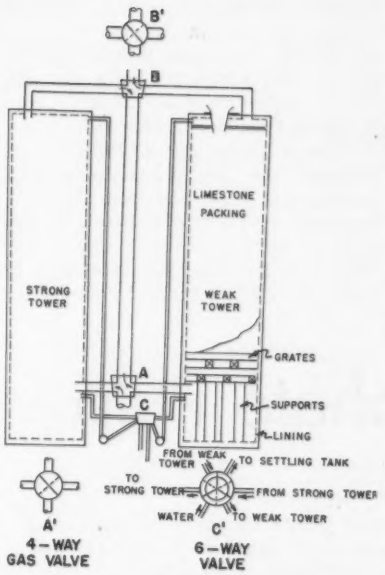


Figure 1

weak tower each day with limestone. When necessary to overhaul one tower, you can operate on the other with some loss of gas. Because the limestone we use is very pure we need to clean out the sludge in the bottom of the towers only every two weeks.

Barker System

A typical Barker tower is shown in *Figure 2,* which is the drawing used by J. G. L. Caulfield in his lecture "Sulphite Pulping, General," Volume one of "The University of Maine Lectures."

The burner gas is drawn in near the bottom of the tank, passes upward through the packing and perforated plates and is exhausted at the top. The lime slurry is pumped in at the top and flows from one compartment to the next through the overflow tubes. The perforations need to be of the right size for the capacity you are operating. This system readily handles dolomite and it is quite common to find this type of lime used, while the Jenssen system usually operates on high calcium lime. Certain advantages in relieving of digesters, in lime deposits, and in quality of pulp are claimed for the milk of lime system over the limestone system. The rate of production of combined SO_2 can be controlled better than in the limestone system.

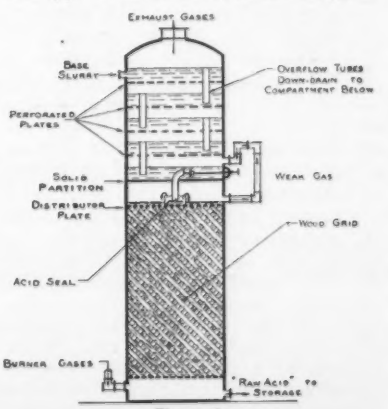


Figure 2
Elements of Barker Acid Tower

As a rule limestone can be purchased cheaper than the lime, and, therefore, the cost of the base is less with limestone. Generally there is some saving in labor, depending upon facilities for handling the base.

A common problem of both systems is to maintain a proper balance between "free" and "combined" SO_2. Water temperature has a considerable effect. A low temperature water used in acid making results in a high ratio of free to combined. For this reason mills have resorted to refrigeration and use of deep wells for a supply of cold water for acid making. In our case it is customary to find a free of 2.00 percent and a combined of 1.30 percent in the summer and a free of 2.30 percent in the winter for the same combined. This can sometimes be compensated for in the absorption system. However, at times it is advisable to use a pressure tower or stripping tower in the acid plant to increase the free content without increasing the combined. Free SO_2 may be absorbed from burner gas under pressure to increase the free to the desired amount. In some cases liquid SO_2 has been purchased in drums or tank cars for this purpose.

Maintenance

In the "old days" maintenance was a tremendous problem in acid plants. However, with the increasing use of stainless steels, particularly, this has become very much less of a problem. Liming of digesters and blow pits may be controlled on a calcium base with careful checking of combined SO_2 and SO_3.

Control Methods

For a great many years the Winkler method had been standard for testing raw and cooking acids for total, free, and combined SO_2. Several years ago we adopted the iodate method of Palmrose which we find more reliable and satisfactory than the Winkler method. The latter method is quite satisfactory for total, however.

Many mills using calcium base experience trouble with liming due to excess combined or to formations of calcium sulphate, or both. Therefore it is important to keep a close check on both. For a rapid routine check on SO_3 in the raw acid we use an adaptation of Raschig's method in which the sulphate is precipitated with benzi-

dine hydrochloride and then titrated with sodium hydroxide. We have generally been able to control the SO_3 to approximately one percent of the total sulphur content of the raw acid as sulphate sulphur.

A further check on SO_3 can be made using the Dupont method on the burner gas itself. This consists of drawing a sample of the burner gas in an evacuated Guillard flask to which had been added a few milliliters of brucine hydrochloride as an inhibitor to stop oxidation of the SO_2 to SO_3. A small amount of water in the flask serves to absorb the SO_2 upon standing a few hours, after which the SO_2 and SO_3 can be determined by titration with iodine and sodium hydroxide.

Various absorption methods are in common use for determining SO_2 losses out of Jenssen towers. They are reasonably good if sufficient time and care is exercised. For a simple routine check an Orsat apparatus may be used. A special burette holding 100 milliliters of gas may be used with the bottom part drawn out and calibrated in tenths of one milliliter instead of being calibrated to two milliliters.

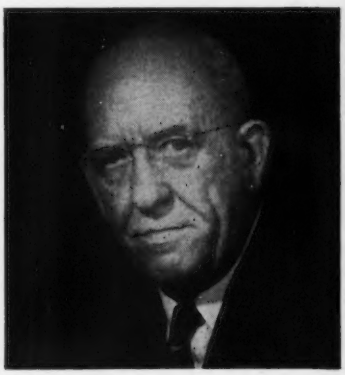
Conclusion

An attempt has been made to describe and compare the various types of sulphite acid that are used in the production of sulphite pulp. Raw materials for the bases, methods of making acid and some operating conditions have also been discussed.

Cooking Sulphate Pulp

R. N. Miller

Technical advisor attached to the Research Department following twenty years as supervisor of pulp and chemical production at Oxford Paper Co. Previous to that, on the Research staff of the Champion Fibre Co. and for five years at the U. S. Forest Products Laboratory under John D. Rue, Chief of the Pulp and Paper Section on research problems connected with the pulping of wood. In between, he has worked in and held executive positions with the Riverside Fibre Co., the Consolidated Water Power and Paper Co. at their Interlake Mill, the Puget Sound Pulp and Timber Co., the Nekoosa-Edwards Paper Co., and the Consolidated Paper Corp., Ltd., at their Port Alfred Division. One year was spent as paper consultant for the Paulista Railroad Co., Sao Paulo, Brazil. Chemical training was at Lawrence College, Appleton, Wis., and the University of Illinois.



Introduction

An attempt to present a discussion of sulfite cooking of wood in an hour and a half exposes one of the dangers of superficiality by condensation or lack of clarity by over simplification. However, in this talk I shall try to tell you something of the raw material to be cooked, the tools used, the procedures of cooking, and the controls applied to guide the operation.

When the sulfite process came into being in about 1870 it came in to a world starved in its paper requirements and in which mechanical pulp or groundwood was already in production. It found apparently boundless quantities of spruce and fir timber. This wood was already in use for mechanical pulp, and what was more natural than the combination of sulfite and mechanical processes operating on the same wood supply to produce printing paper, and other types of paper, as the demand grew. The sulfite process became the chief tool for reducing wood to pulp by chemical means and remained so up to a year or so ago, when it yielded the lead to the sulfate process.

The Raw Material

The sulfite process can be used to reduce the wood of most tree species. The less resinous conifers, however, spruce, fir and hemlock, are the favorite species.

The gross structure of the wood of these species shows a grain running lengthwise of the tree trunk and a ring structure on a horizontal cut surface. The micro-structure of the wood shows a multiplicity of small elements arranged longitudinally and making contact end to end with adjacent elements. These elements are separated by a material of different structure. Passages of larger size running both longitudinally and radially can also be seen. The wood seems to have a porosity in the longitudinal direction greater than that in other directions.

Chemical analysis of the wood shows it to be made up of a large number of chemical entities that can be grouped and an analysis of wood can be expressed as follows.

Cellulose	57.00%
Lignin	28.00.
Pentosans	10.00
Extractions & Ash	5.00
	100.00%

Of these materials the cellulose is the principal and most desirable component of sulfite pulp.

Chemical analysis of the wood and the naming of various groups of constituents is not the only factor that must be considered in setting up a technique for separating the components of wood. It must be remembered that wood is a product of the life and growth of a plant and the chemical constituents are not present as a homogeneous mixture but are present with definite space relationships just as nature formed them and arranged them.

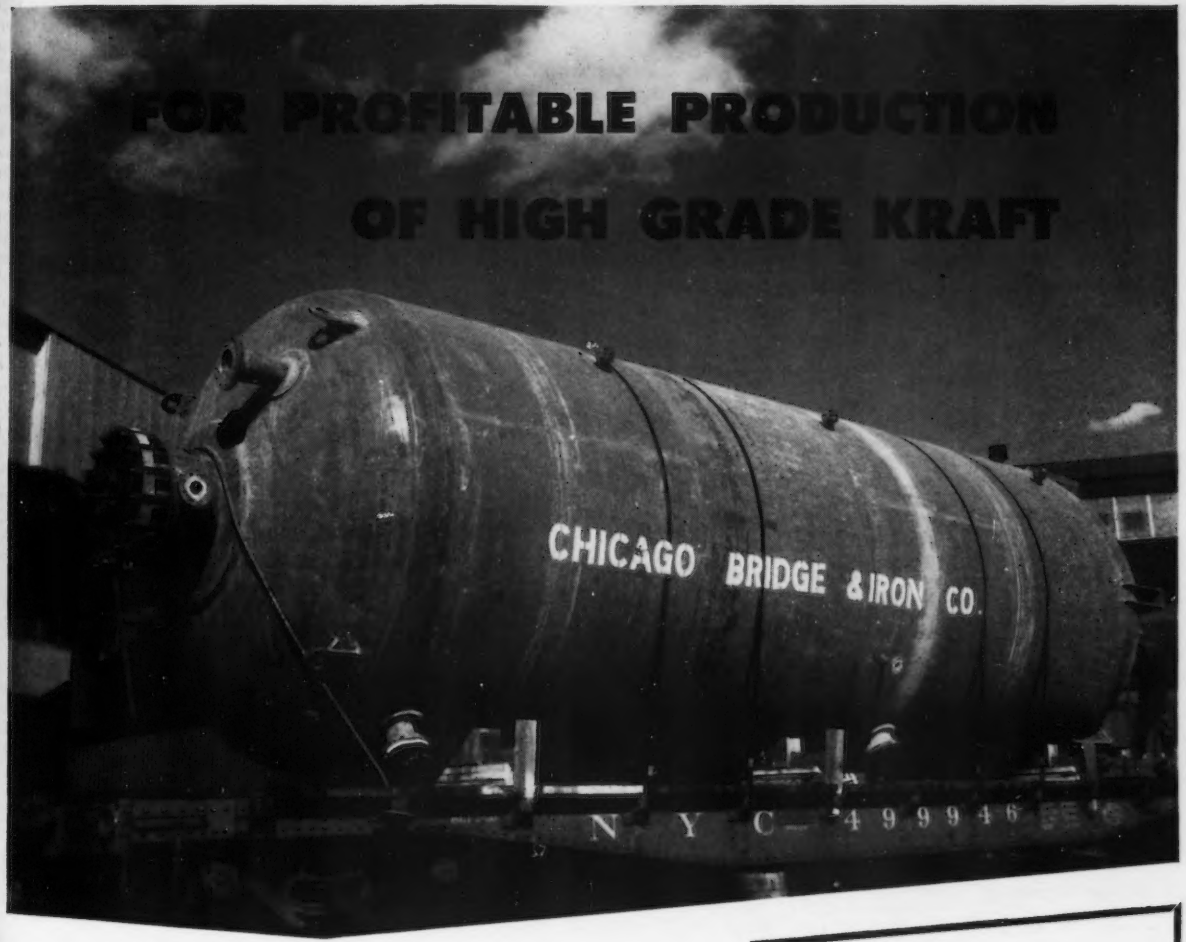
The Tools to Be Used

The chemical with which we propose to resolve the wood is a water solution of a bisulfite with an excess of sulfurous acid. This reagent is capable of reacting in several ways. It can act as an acid and therefore is capable of promoting certain hydrolytic reactions. It can form sulfonic acid compounds with organic compounds both of the aliphatic type and the benzene type. It can act as a reducing agent. It can also exert a pressure of sulfur dioxide resulting from its decomposition at only slightly elevated temperatures.

In a most elementary discussion of the cooking operation it can be said that acid dissolves the incrusting materials and leaves pure cellulose. That is all right for the visitors on a "Blue Line trip" through the mill and in truth you do have a residue that approximates cellulose after the cooking when the rest of the wood has gone down the sewer or into the air.

It is probable that all the reactive capacities of the cooking liquor are employed in a sulfite cook and that none of the constituents of the wood escape entirely unaltered from the environment of the reaction. The technique of cooking is directed to preserve as much of the wood material as is suitable for the product desired, and to eliminate as much as possible of the unsuitable.

The purposes of sulfite pulp cooking are accomplished by bringing together in a suitable vessel a quantity of



Four new Horton* sulphate digesters were recently installed at the Eastport, Florida plant of the St. Regis Kraft Corporation. These new digesters, which are 12 feet in diameter by 46 feet high, will help to increase production of high grade kraft

It is the wise pulp and paper mill operator who constantly keeps his eye to the future by laying careful plans to meet the challenges of increased competition. One of the chief ways to get more efficient operation is to take stock of your present equipment and make the necessary improvements

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wood, reduced to chips as of regular a size as possible, and the bisulfite-sulfurous acid reagent in water solution. The vessel is arranged so that the contents may be heated as desired and so that the temperature and pressure resulting from the heating may be controlled.

The development of vessels in which sulfite pulp can be cooked has been an endless battle with the corrosive action of the cooking chemicals. It has run the gamut of bronze vessels, lead lined iron and steel vessels, ceramic lined steel vessels and is going into vessels of stainless steel and special alloys. Riveted steel plate, single or double buttstrapped, with cast steel end pieces has been the favorite construction for many years but some recently built digesters, as the cooking vessels are called, have been welded steel construction erected in place.

Digesters have not been standardized as to size and the commercial range is from three to thirty-five tons of pulp capacity per cook. Digester shape has not been standardized either, although the perpendicular cylindrical digester with the ratio of height three times the diameter with dome shaped top and cone shaped bottom, are most common. A notable departure is the Mitscherlich digester which is placed in a horizontal position and has rounded ends.

The use of some type of chrome-nickel steel for all attachments to the digester has become practically universal.

Cooking Procedure

A digester ready for commercial use is set up in the general pattern indicated in *Figure 1.*

The cooking operation begins with filling the digester with chips. Modern practice makes use of some form of chip packer. These were introduced first to increase production and from this point of view have been very effective and profitable. They all operate on the principle that if the stream of chips flowing into a digester is scattered the chips will come to rest in a horizontal position and will pack tighter than if they are allowed to fall and form a constantly rising cone as the digester fills. A gain in digester capacity of twenty percent can be made by using a good packer. Having filled the digester with chips the cover is secured in place and warm acid is pumped in through the bottom from the accumulator. It is important that the digester be pumped full, especially if a chip packer has been used, so the pumping is continued until acid runs out the top relief piping and back to the accumulator. It is sometimes claimed that it is advantageous to continue the pumping until at least one full digester charge of acid has passed through the digester and back to the accumulator leaving the digester full. The valve on the acid line at the bottom is then closed, the relief valves are closed, the acid pump is stopped and the digester is ready for steam.

Let it be assumed that we are to make a cook of nine hours duration in a digester that is about 14 feet diameter and 42 feet tall loaded with about twenty tons of wood and about twenty-four thousand gallons of cooking acid. The temperature of the digester contents is between 60 and 70 degrees Centigrade and the pressure at the top of the digester is about 40 pounds per square inch. We wish to make a pulp suitable for book paper when bleached with 4.5–5.0 percent chlorine equivalent. Let us turn on steam and try to avoid our first mistake, that is to turn on too much steam. The digester is quiescent and nearer to equilibrium than it will be again throughout the cook. We seek to create a circulation of the liquid part of the digester contents so that the heat of the steam will be transmitted to all parts of the digester in as near as possible equal amounts. If we have forced circulation the task is easier.

In addition to creating circulation, it is necessary to allow time for the cooking chemical to penetrate the wood. Recalling the wood structure, account must be taken of the fact that the wood, although porous to a certain degree, is compact enough so that penetration of the cooking chemical into the interior of the chips is resisted. Unless the penetration of the chips is complete at a comparatively low temperature an alteration in the lignin of the wood will take place and it will no longer dissolve in the cooking chemical. So, therefore we go slowly, adding steam slowly, but at an increasing rate, with the objective of reaching a temperature of about 110 degrees Centigrade at the end of the second hour. Even though we have forced circulation, the penetration step of the cook cannot be trifled with and the exact rate at which steam can be added is best governed by a predetermined graduated increase in steam flow governed by the indications of a flow meter.

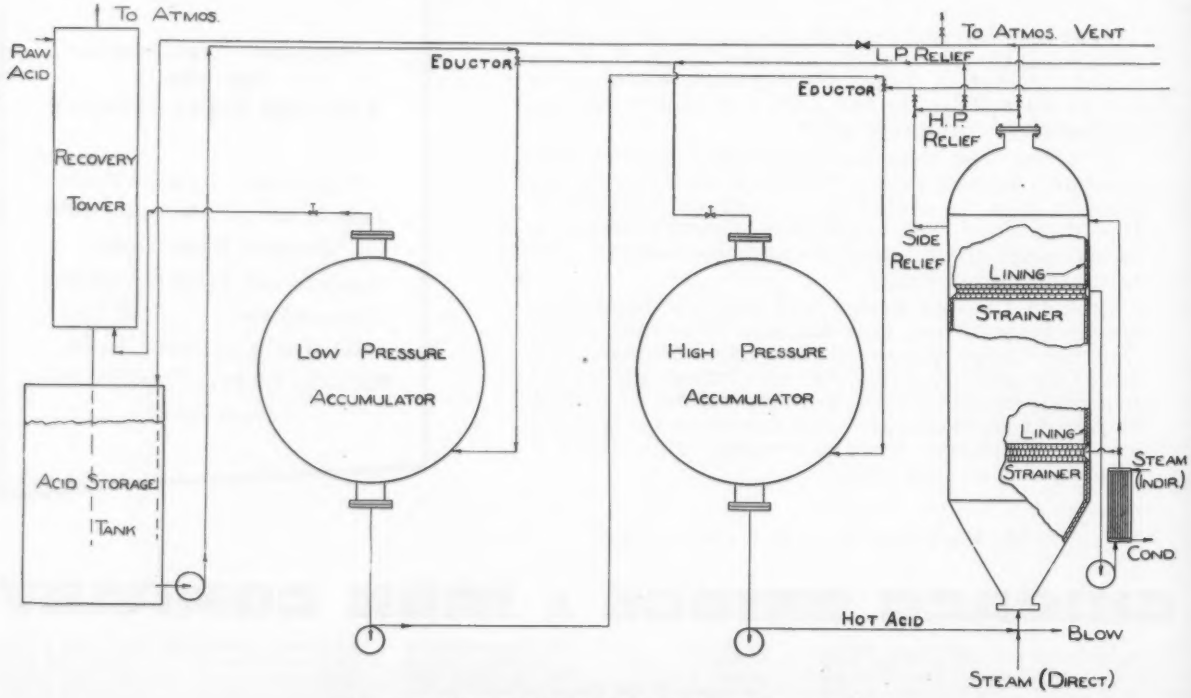

Figure 1. Schematic Diagram Sulfite Cooking and Recovery

When the steam is turned on, the gauges show an almost immediate rise in pressure in the digester. The indicated pressure is higher than that which corresponds to either the vapor pressure of water or sulfur dioxide or both at the temperature indicated on the digester thermometer. This condition must be eliminated, first because we do not want to blow up the digester and second because we want to maintain a steady regulated increase in temperature, whether the heating be by direct or indirect steam. At a pressure of say 70 pounds we open the relief valves and find that there is a flow of liquid through them and that the pressure drops suddenly. This is an indication of a digester full of liquid as we had it after pumping the cooking liquor, and it is necessary to draw out some of this liquor to make room for condensed steam and acid expansion. If cooking with an external heater the need to relieve liquor will not be so pressing.

At this stage of the cooking operation the digester needs close attention from the operator who is concerned with getting the excess liquor out, getting the necessary amount of heat in, and arriving at the end of the penetration phase of the cook with a temperature about 110 degrees Centigrade, a pressure of about 75 pounds per square inch at the top of the digester, and a digester in which the liquor level is as high as possible. It is important to have the pressure higher than 75 pounds per square inch, if possible, because by so doing the sulfur dioxide content of the liquor is maintained high even when the liquor level is lowered to a satisfactory point and an approximate vapor-gas pressure temperature equilibrium is established.

From the end of the penetration stage the cook should continue to manipulate his relief valves and govern his steam flow to cause the digester to perform as desired. While he is doing this let us consider what is happening in the digester.

To describe what happens in a sulfite cook it is necessary to put together many bits of information and the picture that can be drawn, while incomplete, is reasonably satisfying.

Referring to the analysis of the wood that is cooking we are going to obtain as pulp a little less than half of the wood. That quantity will contain mostly cellulose but there will be present some of each of the other units. Furthermore, the mass integrity of cellulose, its fiber structure, will be much as it was in the wood. The small amounts of other materials that were present in the wood can frequently be identified in the cellulose, using microscopic techniques, recalling that the wood with which we started was the result of the elaboration and arrangement of material by a life process in the tree. Having gained less so-called cellulose than had been in the wood, a search for it in the waste liquor reveals fermentable sugars some identical with those formed in the hydrolysis of the cellulose pulp residue. Pentosans are also found in the waste liquor and the corresponding pentose sugars have been identified in the waste liquor as well as in the pulp. It seems quite logical to say that the cellulose, pentosan and the carbohydrates lost from the cellulose have been separated and some of them rendered soluble by a hydrolytic action.

There isn't much lignin left in the pulp but it is found in the waste liquor. The investigations of lignin from waste liquors shows that sulfonic acids and salts of sulfonic acids are present in large amounts and in different forms. Various reactions of decomposition of lignin and lignin sulfonates have yielded splinters that have been identified but no one has put a definite label on lignin. The view of Klason expressed many years ago that lignin was of large molecular weight and composed of units of coniferyl alcohol and coniferyl aldehyde is still as good as any, but recent investigations seem to be leading to a definite characterization of the material called lignin. Certainly there is no doubt that sulfonic acids of lignin are formed in sulfite cooking and that the decompositions and combinations that lignin undergoes in the environment of a sulfite cook are such that only close adherence to the fundamental techniques that have been developed will yield pulp of controlled desirable properties.

Haglund in a recent review of the sulfonation of lignin expresses the view that sulfonation precedes a hydrolysis that renders the lignin soluble and that in the environment of the sulfite cook there is a simultaneous condensation of elements through the very groups that may be sulfonated. The successful completion of a sulfite cook seems to depend on the satisfying of these groups by sulfonation and neutralization of the sulfonic acids followed by an acid hydrolysis.

Richter has recently shown that pretreatment of wood with sulfites, or strong sulfurous acid, improves the cookability of the wood and that some other treatments, notably weak sulfurous acid, make subsequent cooking difficult or impossible.

We can now resume the cooking of our digester with a basis for understanding why the technique is successful.

The penetration of the wood by the acid has been spoken of in terms of entry of the acid into the interstices of the wood. A further penetration of the acid into the substance of the wood must take place before appreciable elevation of temperature takes place. This penetration is the phenomenon investigated by Richter in his exploration of pretreatments. In our digester we have both a bisulfite, calcium bisulfite we'll say, and a strong sulfurous acid. If we maintain a moderately low temperature for say three hours it is probable that this preparatory action is completed and the reactions suggested by Haglund started. The digester at the end of the fifth hour should be at about 130 degrees Centigrade and pressure 75-80 pounds. The reactions mentioned by Haglund, sulfonation, condensation and hydrolysis are proceeding actively. The cook has manipulated his relief valves, both side and top so that the pressure shown at the top of the digester is that which approximates equillibrium of gas and steam pressure and it is time to consider how the digester is to be finished off.

We started to make a nine hour cook and experience shows that we do not have to heat the digester to a much higher temperature than 140 degrees Centigrade. We do have to recover a lot of sulfur, however, and the manipulations from now on are directed to discharging as much as possible of the sulfur as sulfur dioxide still present in the digester to the recovery equipment at such a rate as to complete the operation at the time the wood is pulped. The cook, therefore, relieves gas and steam from the top of the digester and regulates his steam flow to cause the temperature to continue to rise slowly. At this stage in the cook, forced circulation begins to fail because the wood is so softened that it restricts the flow through the strainers. However, the relief of gas from the top of the digester causes an upward flow of gas in the digester and circulation may actually be better and equilibrium more nearly obtained. The relief pipes will sing and the cook will feel and can sense an increased activity in the digester. He should be making tests of his digester liquor to see if the acid strength is going down at a suitable rate and adjust his relief accordingly. Temperature will be approaching the maximum desired and steam can be much reduced or shut off. At the seventh hour the temperature will be near 140 degrees Centigrade and the cook will open his relief valve to reduce pressure and recover gas, aiming to have the pressure reduced to about 40 pounds at the ninth hour. At the ninth hour approaches he will make frequent observations of liquor samples and possibly pulp samples and will combine his skilled experience, and the information from his tests into a decision to blow the digester. A well handled cook will be blown within fifteen minutes of the hour appointed.

Controls

At this point it is appropriate to consider the means the cook has at his disposal for keeping himself informed as to the progress of the cooking reaction and for guiding his activities. The means are divided into two parts, the recording and the indicating instruments and the observation that can be made on samples withdrawn from the digester.

The minimum instrumentation for a sulfite digester should be a recording thermometer, a recording pressure gauge and a recording steam flowmeter. From there you can go to about any extreme you may wish. A system can be set up for a completely automatic cooking operation. Some such systems are in use and in them the pressure is controlled by an automatic valve connected to the pressure recorder and controller, the temperature can be controlled by an automatic valve on the steam line and activated by changes in temperature or steam flow. The digester can be blown through a blow valve activated by a motor started by remote control. The continued success of such an operation depends upon uniform conditions from cook to cook, a situation rarely realized.

The testing of samples drawn from the digester begins while the digester is being pumped. A sample of the cooking acid is drawn through a cooler and tested to determine the amount of sulfurous acid and, usually, calcium bisulfite. From previous lectures you have learned about the testing methods applied to acid testing and the same methods can be used in testing this first sample from the digester. However, because the cooking acid contains a quantity of waste liquor it is more accurate to titrate with iodine for the total sulfurous acid and use the Sander Method for the bisulfite.

As the cooking progresses the cook will note that the liquor at first becomes lighter colored and later darkens progressively through pale straw-colors to light reddish brown. At about the fifth hour the liquor becomes brown and if the wood being cooked is hemlock, the color viewer by light transmitted through the sample will have a distinct red tinge. After the seventh hour the color will darken rapidly and the liquor will become somewhat muddy. Tests with iodine titration will show a marked reduction early in the cook. In fact by the time the fourth or fifth hour is reached and the cook has reduced the liquid level in the digester the iodine test will indicate that a very large part of the sulfur dioxide is gone regardless of how high it was to start with. What has happened is that much sulfur dioxide has been relieved and recovered and some absorbed by the wood. An approach to equilibrium between gas and steam pressure and composition of the liquor at the existing temperature has been established.

If the Sander method is applied to the analysis of the liquor systematically after about the fifth hour it will be found that it indicates a progressive decline in the amount of bisulfite present in the liquor. In fact the decline in bisulfite will parallel the darkening of the liquor. This happy circumstance makes it possible for an experienced cook to judge by the color of the liquor how near the digestion action is to the point at which he must blow the digester to avoid a spoiled cook.

Many efforts have been made to test the pulp contents of the digester but I know of no method that has been universally accepted and used. After all, as long as there is no homogeneity to the digester contents it seems unlikely that any sample of pulp will be representative and furthermore there is no test known that can be made fast enough to do the cook much good at the critical stages in a cooking operation. About the only way to approach a uniform operation is to establish a uniform technique and guide it by means of instrument records and tests that can be applied and interpreted quickly.

Recovery

A necessary adjunct to the cooking operation is the recovery of heat and excess chemicals. The acid charged to the digester carries much more chemical than is needed to complete the cook. Recovery of these values is carried on about as follows:

Referring to *Figure 1,* you will note that there is a connection marked "Side Relief" and one from the top of the digester that is divided and marked "H. P. Relief" and "L. P. Relief." There is a further line marked "TO ATMOS VENT." When the digester is pumped full of acid through the line marked "HOT ACID" the line leading to atmosphere at the top of the digester is open so that the air in the digester may escape. All other relief valves are closed. When the digester is full, as indicated by a discharge of acid from the atmosphere vent, this vent is closed and relief lines leading to the accumulator are opened. It is now possible to circulate hot acid from the High Pressure Accumulator through the digester and back to the High Pressure Accumulator. This operation should be prolonged at least long enough to make sure that the digester is full of acid. Benefits that may be attributed to further circulation of acid must be balanced against time that may be lost from the cooking cycle.

When the digester is full of acid, steam is turned on and an immediate rise in pressure makes it necessary to hold the pressure down, both to prevent too high a pressure and to permit free entry of steam if direct steaming is in vogue. The liquid relieved from the top of the digester and returned to the Hot Acid Accumulator is the first element in the recovery operation. If this operation is continued through the top relief connection at a rate that holds digester pressure at the desired point the level of liquid in the digester will remain at the highest possible point and steam can enter at a rate suitable for the cooking schedule if steam at high enough pressure is provided. The material returned to the Hot Acid Accumulator during this period in the cook is a mixture of liquid, gas and steam and it is being joined at the eductor by the relief from the other digesters on the line and acid which is being pumped from the Low Pressure accumulator.

The next step in the recovery process is the drawing of side relief. There is only one basic reason for side relief from the standpoint of cooking technique though many variations are practiced from the standpoints of steam economy or other less valid reasons. The purpose of side relief is to lower the liquor level to such a point that so-called dry gas, which is a mixture of steam and sulfur dioxide at temperatures usually above 130 degrees Centigrade, can be relieved to the accumulators in time to recover most of the unreacted sulfur dioxide remaining in the digester before the cook must be blown. The side relief should be finished at least two hours before the time to blow the cook.

The final phase of the recovery operation is the blow down. During this phase every effort is made to recover all the available sulfur dioxide remaining in the digester. The relief is composed of steam and sulfur dioxide and considerable quantities of carbon dioxide. These gases can be passed to the high pressure accumulator to advantage as long as there is enough pressure differential between the digester and the accumulator. When this is not true the relief is diverted to the low pressure accumulator. The completion of the recovery occurs when the relation between temperature and steam pressure in the digester is that for saturated steam over water.

The recovery operation from the digester side must be accompanied by operations on the accumulator and acid storage side of the system. These operations involve retaining the wet relief in the high pressure accumulator and passing the surplus gases from the high pressure accumulator to the low pressure accumulator to the reclaiming tower and to the acid storage in order. At the same time, a stream of acid is passing countercurrent through the reclaiming tower, the acid storage, the low pressure accumulator and to the high pressure accumulator by way of the Eductor which is located in the high pressure relief line just ahead of the high pressure accumulator.

The stream of acid enters the reclaiming tower at the temperature at which raw acid is produced in the acid plant, usually not over 21-22 degrees Centigrade. At this temperature it absorbs the excess gas from the low pressure accumulator, and is raised slightly in temperature. The pressure in the low pressure accumulator is usually at 15 pounds. From the acid storage, which is a sort of surge tank in the system the acid is pumped to the low pressure accumulator which is kept at a constant level, nearly full. Here the temperature of the acid and the sulfur dioxide content is raised by the entry of the low pressure relief

and the overgas from the high pressure accumulator.

The acid from the low pressure accumulator is pumped to the high pressure accumulator through the eductor in the high pressure relief line at a rate such that the high pressure accumulator is nearly full of acid when a digester is ready for pumping. The accumulator at that time may be at about 50 pounds pressure and 65-70 degrees Centigrade temperature.

The results of the operation are subject to much variation but in a normally operating mill the acid starting in the acid plant at 22 degrees Centigrade and of the analysis, 4.00 percent Total, 2.60 percent Free and 1.40 percent Combined sulfur dioxide will have become 8.00-9.00 percent Total, 7.00-8 percent Free and 1.00 percent Combined sulfur dioxide in the accumulator.

Sulfite Pulping

Frank Harlow[1]

Graduate of Bowdoin College 1929. With present company since 1930 as assistant chemist, night superintendent soda division, assistant sulphite superintendent and as superintendent of sulphite division since 1935.

Introduction

Benjamin P. Tilghman, an American chemist, discovered in 1866 that it is possible to cook wood with a solution of sulfur dioxide in water. His first attempts in cooking wood in this solution resulted in a dark pulp that was very difficult to bleach. Analysis of the resulting waste liquor showed the presence of sulfuric acid. In order to neutralize that sulfuric acid, which is formed in the cooking, he added lime to the cooking solution. This resulted in a much lighter, easy-bleaching pulp. The following year he patented this process of cooking wood with a solution of sulfur dioxide in water, with or without the addition of an alkaline bisulfite. These patents also included the recovery of the sulfur dioxide gases at the end of the cooking by absorbing them in water. Several other men claimed the discovery of this same process at a later date with minor variations in procedures. Among them were C. D. Ekman, a Swedish chemist, and two Austrians, Eugen Ritter and Carl Kellner. Various standard texts contain a complete history of this development.

I should like to explain the mechanics of sulfite pulping by referring to a drawing of a digester and equipment, *Figure 1*. The necessary items of equipment will be taken up in a logical sequence. This will include the recovery end of sulfite pulping. The discussion is based on the process and equipment used at the Penobscot Chemical Fibre Company: a vertical digester, direct steaming, no forced circulation, calcium base acid, and a hot acid system.

[1] Superintendent, Sulfite Division, Penobscot Chemical Fibre Co., Great Works, Maine

Digester

We will start in with what we call the top nozzle, sometimes known as a sleeve, at the top of the digester, and with the bottom nozzle. Generally these nozzles are made of type 316 stainless steel. Digesters were originally lined with lead because lead is very acid resistant. However, it was found that the lead will expand out of place. Copper and bronze alloys also were used for a long while. Today, however, stainless steel is the material of choice for digester fittings.

It is necessary to line the digester body with acid resistant material if the entire digester is not fabricated from stainless steel. Some mills use a double course lining; some use the single course lining. This lining is made of acid resistant brick set in joints of litharge. The litharge joint compound is composed of one part litharge, one part cement, and one half part fine quartz. The dry materials are mixed with glycerine to form a heavy sticky cement which is applied to the joints. In the space between the shell of the digester and the brick is run a cement backing composed of cement and a medium particle size quartz. The space between the side of the digester and the top nozzle is filled with the same cement mixture. A double course lining is illustrated in *Figure 2*. Such a lining is about seven and one half inches in total thickness. The face course should serve for 10 to 12 years.

Some mills favor a single course lining. There is always the danger, however, that acid may get back into the shell if the lining wears through unexpectedly. Dangerous weakening of the carbon steel shell may result.

The operation of the recovery system to produce these results must receive as closs attention as the cooking operation. In fact the entire combined operations must be looked upon as a closely integrated unit, the successful operation of which must be of the nature of a systematic, cyclic, unit operation the purpose of which is, after all, the production of suitable sulfite pulp.

The top nozzle is 24 inches inside diameter. The one at the bottom is 10 inches across. It is necessary to have a large enough opening at the top so that a workman can get down into the digester. Men have to go in there to inspect the lining and do the relining work. This size opening seems to be about the smallest practicable size. The 10 inch opening at the bottom is necessary for the removal of pulp. A so-called blow line is provided for the removal of the cooked chips. During the cook, material is retained in the digester; at the conclusion of the cook the valve in the blow line, which is a "Y" valve, is opened and cooked material blown out by the pressure remaining in the digester. As operated at our mill, our digesters, which are 15 feet in diameter, and 50 feet in height, produce about 21,000 to 22,000 pounds of pulp per blow (bleached basis). This is from a charge of some 22 to 23 cords of wood.

Digester Cycle

Filling Digester with Chips

Let us now go through an entire digester cycle and discuss details of the equipment as we go along.

The first step in the cycle, of course, is the charging of chips to the digester through the top nozzle. This operation is much more than merely dropping wood chips into the digester from an overhead bin. Packing of the chips in the digester is of great importance in determining the daily production of the mill, as well as in steam and sulfur economy. Our mill operates with natural circulation in the digesters so we must be careful not to hamper circulation by uneven or too dense packing. Digesters operated with

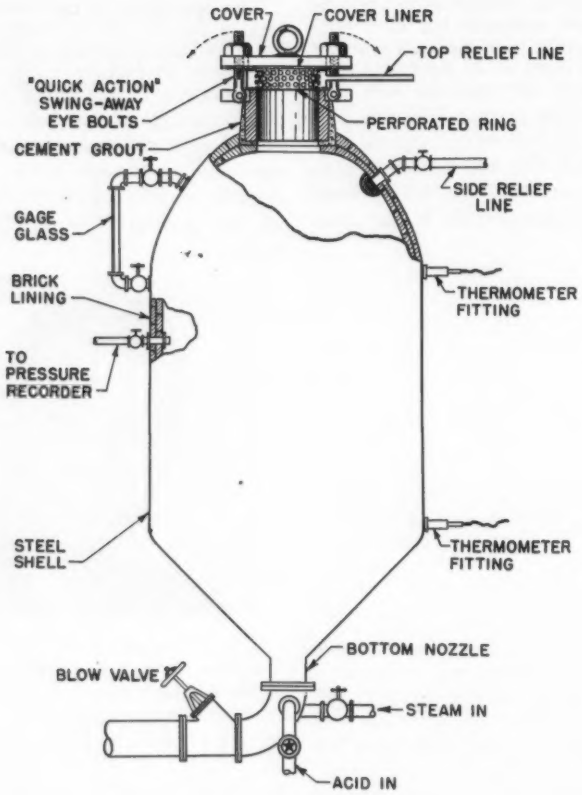

Figure 1—Digester and Equipment

forced circulation may be packed to a greater density.

Several factors affect the packing of chips: In the first place, chips from a dense species of wood will pack harder than those from a lighter species simply because of the sheer weight of the chips above tending to pack down those below. Secondly, there is a difference in the packing of wet and dry chips. Thirdly, rate of filling also affects packing density. The slower the rate of filling, the greater chance for the chips to pack down. There is another objection to too rapid filling, aside from low packing density: that is, if chips are fed too fast packing will not be uniform. This, of course, leads to circulation troubles.

In view of these circumstances we use a steam jet through the top nozzle to distribute the chips more or less uniformly around the digester, avoiding the pyramid effect that would otherwise occur with straight dumping. We do not introduce steam at the bottom during filling, an operation known as "bumping," to settle the chips. This procedure is followed in some mills having forced circulation. With natural circulation this procedure would result in the chips being packed too much at the bottom for good circulation. With normal filling, little or no packing, about 15 pounds of chips can be packed per cubic foot of digester capacity. Some mills using highly efficient packing methods have achieved packing as high as 18 pounds per cubic foot. If adequate provisions for forced circulation exist, the more dense packing can result in improved steam and sulfur economy, as well as in a higher yield per digester. But, even with forced circulation, there is a limit to the degree of packing that can be achieved without interfering with the flow of heat and acid through the digester.

Addition of Acid

After the chips have been fully loaded into the digester, the next step is the addition of the cooking acid. The majority of mills today employ the so-called hot acid system of acid supply for the purposes of heat and chemicals recovery. The essential item in a hot acid system is the accumulator, a spherical steel pressure vessel, lined with acid resistant brick. The construction of the accumulator is almost identical with that of a digester except that the lining brick must be less porous than that used in digester installations. It is usually considered desirable that the accumulator have an acid capacity of from one and one third to three digester charges of acid.

Acid making plants were discussed in a previous lecture; therefore we will follow the course of the acid from where it leaves the acid plant to the digester (See *Figure 3*). Upon leaving the acid making system, the raw acid first goes to a constant level tank and then passes to storage. We use acid storage tanks of wood stave construction, the material being western fir. These tanks are 24 feet in diameter by 30 feet high. From storage, acid is pumped continuously to the accumulator by means of a direct connected, chrome-nickel steel pump, called the cold-acid or accumulator pump. In our mill the pump is rated at 200 gallons per minute at a 165 foot head.

High pressure top and side relief from the digesters joins this cold acid stream and both enter in the lower part of the accumulator. When fortified cooking acid is required to charge a digester, the charging pump, which draws from a line connected to the very bottom of the accumulator, is started up. This digester acid pump is usually a single stage, double suction pump with a horizontally split casing and a deep packing gland to take care of high pressure on the *suction* side. Remember that the accumulator may be under a pressure of 35 to 50 pounds per square inch gauge. In our mill the pump is rated at 2000 gallons per minute at a 65 foot head. A 50 horsepower motor drives it at 1200 revolutions per minute. Between 25,000 and 30,000 gallons of acid are required to fill the digester, depending on the amount of packing.

Before we actually start to pump the

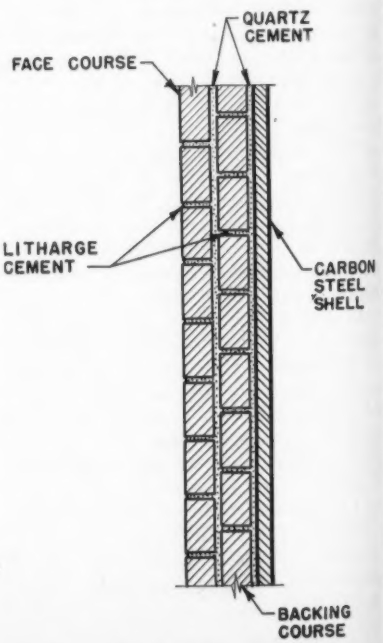

Figure 2—Double Course Lining

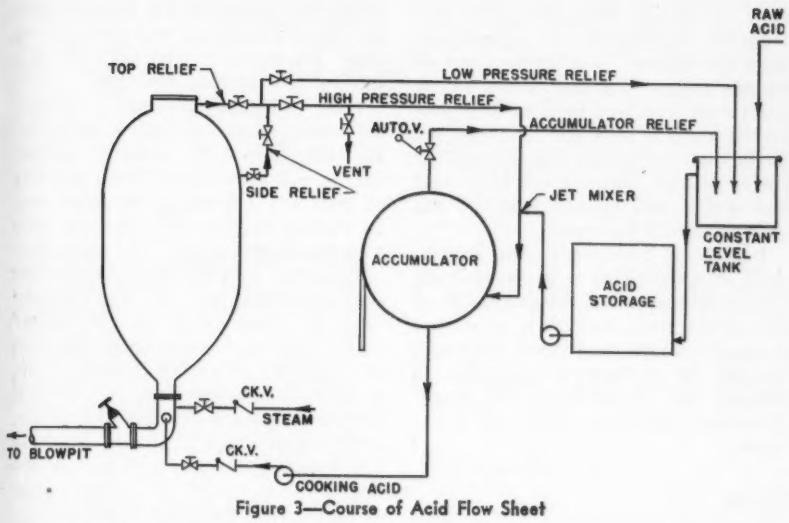

Figure 3—Course of Acid Flow Sheet

acid into the digester, we had better bolt the cover on. I should like to point out to you some of the construction details of this strainer assembly, which is of Swedish design. The top strainer consists of a perforated ring, the size of the top sleeve. This ring is surrounded by another ring of larger diameter, which, however, is not perforated. The top relief line is connected through the outer ring to the annular space between. (This is shown in *Figure 1.)* This strainer is made of stainless steel, as is the cover liner that goes over it. The final item in the cover assembly is the high-tensile steel cover itself. During the chip loading operation, the cover and liner are swung out of the way by means of a chain hoist. After the chips are all in, it is a matter of but a few moments to lower the cover in place and secure it by means of eye bolts.

As acid is pumped into the digester, air must be allowed to escape. A vent to the atmosphere is therefore opened to the top-relief line just described. The rate of pumping of acid is so rapid that it is not unusual for 35 pounds pressure to build up in the digester during pumping, even with the vent wide open. The function of the strainer in this and subsequent relief operations should be obvious. Were there no strainer present, chips would soon clog the line.

One further word about acid charging: Between the digester acid pump and the point where the line joins the bottom fitting, the so-called "bottom cross" of the digester, it is essential to install a check valve in addition to the usual shut-off valve. This is to prevent the blowing back of chips into the line should the digester acid pump go down unexpectedly. I can testify to the unpleasant consequences of permitting chips to blow back into the acid line.

Cooking

With a full charge of acid in the digester, we are ready to begin the cook. The information of particular importance to the operator during the cook is the pressure, the temperature, and the liquid level inside the digester. Acid level is very simply determined by means of a gauge glass located on the upper part of the digester. For pressure operation, these gauge glasses must be equipped with shut-off valves. Liquid-level recorders are becoming popular in some places. However, these are quite expensive in comparison with the common gauge glass.

Fittings for temperature and pressure measurements are usually of the replaceable insert type. It is desirable to record pressure on a circular chart instrument. Temperature is recorded on a common chart from at least two points in the digester. Our temperature fittings usually permit the bulb to extend some 12 inches into the chips. If we locate two such fittings in the digester, one above the bottom cone and one just below the top cone, we may not be sure what the temperature is everywhere in the digester but at least have an idea what is happening at two representative points. Our temperature fittings are so constructed that a calibrated glass thermometer may be inserted to check the performance of the recording thermometer.

Steam is admitted to the digester through the bottom fitting from a steam line equipped with a check valve, just as is the acid line. It is even more important to prevent blowback in case of steam pressure failure than in the previous case. Blowback of acid into the steam lines could cause severe damage.

In the initial stages of cooking, considerable gas is evolved, which generates excess pressure. When the digester pressure reaches about 75 pounds, excess pressure is valved out through the high-pressure relief line to the accumulator. I think you can see that the condensation of steam in the digester will increase the liquid volume in the digester, with the result that the top relief in the initial stages will have both gas and acid content. All this relief may increase the pressure in the accumulator to the extent that relief from the accumulator is needed. A line from the top of the accumulator provides relief; for chemical economy this accumulator relief is fed to the constant level acid tank (See *Figure 3*). The net effect of this two stage relief is a countercurrent fortification of the acid with sulfur dioxide.

The initial stages of cooking are devoted to the process of penetration of the chips by the cooking liquor. It is extremely important that all the calcium bisulfite buffer be in the chips before the actual cooking action begins to take place. In other words, we must be sure that all the combined

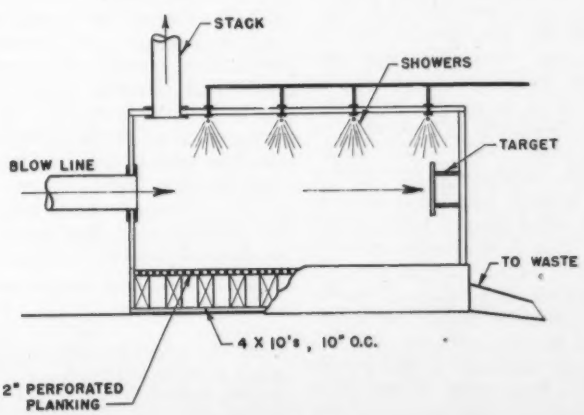

Figure 4—Blow-Pit

has penetrated the chips before the critical temperature for the reaction of free acid with the lignocellulose is exceeded. In the presence of sufficient bisulfite, the lignosulfonic acid formed by the reaction of sulfurous acid and wood is soluble. If sufficient bisulfite is not present, however, a dark, insoluble material is formed which cannot be conveniently removed by subsequent treatment. Also, if the temperature is raised too high in the absence of bisulfite, acid hydrolysis of the cellulose may take place. The critical temperature for the cooking reaction is 221 degrees Fahrenheit. Since penetration takes place more readily the hotter the acid, it is common practice to raise the temperature in the digester to a point just below this critical level and maintain it until penetration is complete.

It is necessary to have a considerable excess of free sulfur dioxide in order to keep the combined in solution. This is one reason for acid fortification in the accumulator; it just would not be possible to get in enough sulfur dioxide at atmospheric pressure. It is also important to have a large amount of free so that there will be sufficient sulfurous acid to dissolve the lignin content of the chips after relief losses have been accounted for.

Our practice calls for a slow increase in temperature over a period of five and one half hours. At the end of that time the maximum cooking temperature of around 284 degrees Fahrenheit is reached. This maximum temperature depends on the total length of cook and type of pulp desired. 284 degrees Fahrenheit is about right for an easy-bleaching pulp of good strength in a 10 hour cook. If a shorter cooking cycle is desired, a higher maximum temperature is needed to assure complete cooking.

I might add that prior to the last stage of cooking, the acid level is drawn down in the digester so as to leave a gas pocket at the top. Relief in the early stages consists of a mixture of acid and gas; this is not too easily controlled. As cooking gets under way, the chips settle some in the digester so it is no longer necessary to have it absolutely full of acid to cover the chips. "Side relief" liquor is therefore drawn off through a strainer at a point just below the top cone. Top relief in the later stages of cooking, therefore, consists entirely of gas, and is quite readily controlled.

After cooking temperature is reached it is possible to reduce the steam supply and let the contents sort of simmer along until about the eighth hour of a ten hour cook. At that time it is necessary to start removing the excess sulfur dioxide as gas. This is done by slowly "blowing down" gas from the digester to the accumulator until the digester is down to about 45 pounds gauge. Further blowdown of gas to the constant level tank is permitted until a pressure of about ten pounds is reached. In this way all the sulfur dioxide that has not been used and which will readily flash off has been recovered for reuse.

I wish to reemphasize the importance of maintaining a proper balance of free and combined sulfur dioxide all during the cook. Failure to do so may result in undercooked wood, with high rejects, in a "burned" cook, or in "liming out", the precipitation of calcium monosulfite on fittings and equipment.

Blowing

After the cooking of the wood is complete, it is desirable to remove the product from the digester in the easiest way possible. That easy way is to utilize the pressure remaining in the digester to blow out the cooked chips. The cooked material still has the physical shape of the original chips even though the cementing substance has been dissolved. Advantage may be taken of the violence of the blow to pulp up the chips to a mass of fiber. Lastly the solublized cementing material (in the form of calcium lignosulfonate) must be separated from the fibrous product. All three of these functions are taken into account in the design of a blow-pit (See *Figure 4*).

In order to provide for accidental delays in subsequent operations the blow-pit for a digester should be able to hold the pulp from something more than two blows. Our pits, which are 42 feet long and 26 feet wide will hold about two and one half digester charges. The blow-pit has a perforated false bottom to permit the drain-off of waste liquor and wash water. The bottoms of our pits consist of two-inch hard pine planks drilled with one sixteenth inch holes. These planks are laid over shaped four by tens set edgewise on about ten inch centers. Today, most mills employ false bottoms of perforated stainless steel plates. At the end of the blow-pit is a target, a large block of wood covered with a stainless steel plate. This target is set opposite the blow line so that the stream of cooked chips rushing out of the digester must impinge on it. This mechanical action, coupled with the sudden expansion of the steam within the chips, effectively reduces them to pulp. Overhead in the blow-pit is a shower for washing the pulp.

Prior to actually blowing a digester, we admit steam to loosen the chips for the blow. A properly cooked charge will blow clean. Small amounts of pulp left behind by the blow may be flushed out into the blow-pit with a stream of water.

With the blowing of the pulp and the ventilating of the digester, we have completed a digester cycle. After being drained of waste liquor and then washed free of residual soluble compounds in the blow-pit, the pulp is flushed into the riffler and screen system. From there it usually goes to the bleach plant for purification and improvement in color. These topics are subjects for another lecture.

Notes on Operating Conditions

Several comments on various aspects of the conditions of operation may be of interest to you. You will recall that I mentioned the countercurrent fortification of acid with sulfur dioxide, which takes place in the relief system. In *Table I*, I have given typical acid analyses at three points in the system.

The figures in this table show the great advantage of using such a system in reaching a level of sulfur dioxide content desired for cooking.

It should be noted that one of the principal reasons for using a pressurized accumulator is that there is only so much free sulfur dioxide that can be dissolved in acid of a given combined content at atmospheric pressure. This amount decreases as temperature is increased. Complete information on this topic is available in the TAPPI Data Sheets. I should like to quote representative figures to show the contrast. At 104 degrees Fahrenheit the maximum free obtainable at atmospheric pressure in our acid is 4.75 per cent, at 168 degrees Fahrenheit this figure is much lower. Now, in an accumulator at only 28 pounds gauge pressure the maximum free at 168 degrees Fahrenheit is 5.35 per cent, quite an improvement. You may readily see that the 4.85 per cent free we use for cooking could not be obtained even at 104 degrees Fahrenheit without the use of an accumulator.

In operation, the addition of steam and the relieving of pressure is largely

TABLE I

Acid Sample	Total SO_2	Free SO_2	Combined SO_2
Raw Acid (from Acid Plant)	3.20	1.80	1.40
Partially Fortified (from Constant Level Tank)	5.00	3.70	1.30
Cooking Acid (from Accumulator)	6.00	4.85	1.15

left to automatic controllers. Our digesters are equipped with cam operated steam-flow controllers which admit steam according to a predetermined schedule. The top relief valve automatically opens at 75 pounds pressure, it does a very good job of maintaining constant pressure during the cook. In spite of such devices the attention of experienced cooks is required to assure quality production. In the last analysis, pulp is only as good as the men who make it.

Conclusion

To sum up, I have attemped to give you an idea of the actual process of digester operation in the sulfite process from the point of view of my own experience in the Penobscot Chemical Fibre Co. mill. From one mill to the next, you will encounter many minor and a few major variations in the sulfite process, but the principles underlying that which we have discussed today will always be the same.

Neutral Sulfite Semi-Chemical Pulping

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Introduction

The title of this lecture is listed as "SemiChemical Pulping." Broadly, that term covers all processes in which wood is partially cooked or softened, with the remainder of the pulping being done by mechanical means. More narrowly, from the standpoint of the industry today, semichemical pulping means the neutral sulfite semichemical process, or N.S.S.C. pulping. There are both acid sulfite and sulfate semichemical pulps being made today, but they have not exhibited the properties and growth that make the N.S.S.C. process of such importance.

Investigating the historical background of this process, we find that Cross and Bevan were aware that sodium sulfite was a pulping agent, and they patented a cooking process for jute and wood in 1880. Very little more was done wih this method until the early 1920's when the United States Forest Products Laboratory began a series of investigations. These culminated in the process which was patented in 1926 and which was first used to make nine point corrugating board from chestnut chips which had been extracted for tannin. The process was successful and took hold across the South, at first exclusively on chestnut, and then, as the chestnut blight became felt, spreading to other hardwoods.

For years the pulp was used entirely for board and unbleached grades. Then in the late 1930's, the Forest Products Laboratory conducted a series of studies on holocellulose which indicated the tremendous potential in the material, and the feasibility of N.S.S.C. pulp as a starting point. Since the laboratory procedure for holocellulose preparation is involved and expensive, multistage bleaching methods were adapted to the purpose. The first N.S.S.C. bleaching was done commercially in the middle 1940's, and was an immediate success. Exploratory and investigative work increased, until today the process is entering a period of tremendous growth.

This growth is due largely to economic reasons. The pulp industry in this country started in the East, spread to the Mid-West, then leaped to the Far West and the South. Today the East and Mid-West have ceased building new pulp mills, and even the Far West and South are becoming saturated. The woodpulp industry in this country is based on long fibered coniferous woods, and these have not proved inexhaustible. The mills cut wood farther and farther away, at higher and higher costs, until the point was reached where foreign producers could deliver pulp to the paper mill cheaper than the pulp mill right alongside could make it. Even with reforestation, the demand for pulp has increased so much that coniferous wood is simply not adequate. Meanwhile the hardwoods have been little used for pulp, since their short fibers, by conventional processes, give pulps which are best regarded as fillers. Consequently the hardwoods have in many places taken over land that was formerly in spruce or pine, offering a further obstacle to reforestation.

The N.S.S.C. process then comes on the scene. It is by nature peculiarly suited to the hardwoods, and it produces a pulp that is quite capable of displacing coniferous pulp in many uses. Add the fact that it is competitive in cost, and the reasons for the sudden spurt in N.S.S.C. interest, particularly in the East, Mid-West, and South, become quite clear.

Wood Species

As has been mentioned, the hardwoods are the number one problem in the eastern half of the country. Their prime drawback is the fiber length, which ranges from about two millimeters down, prohibiting high strength values by conventional chemical processes. As a group, they run lower in lignin, lower in alpha cellulose, and higher in hemicellulose than do the softwoods. The lower lignin content is to their advantage, but the hemicellulose content is largely lost in chemical pulping. The N.S.S.C. process retains much of these hemicelluloses, thus giving a greater yield. Lignin is a strength-giving binder in the tree, but exerts no useful effect in paper pulp. When it is removed by bleaching the

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hemicelluloses which remain have been freed and apparently act as a strength-giving cement in the pulp, largely overcoming the disadvantages due to the short fiber length. The N.S.S.C. process is not too well adapted to coniferous woods, because of their high lignin and low hemicellulose contents, which limit the yield advantage and cause difficulty in bleaching. In addition, such resinous woods as pine are resolved with difficulty by the N.S.S.C. process, although some commercial runs of board pulp have been made.

Wood Preparation

Wood preparation follows conventional procedure for chemical processes, and is so indicated on the flow sheet, *Figure 1.* Probably the number one problem, particularly for bleached grades, is bark removal. The N.S.S.C. process is not as effective as the kraft process in bark removal during cooking, and hardwoods in general are more difficult to debark than the coniferous woods. Experimentation is continuing with barking methods. A development which is attracting considerable attention is chemical debarking, wherein the standing tree is girdled and treated to loosen the bark, enabling easy removal during normal handling or with light mechanical treatment at the mill.

Barking has been found desirable even for board grades. Most hardwoods are nondurable, and unbarked wood deteriorates much more rapidly in storage than does barked or peeled wood.

Liquor Preparation

The preparation of N.S.S.C. cooking liquors is very simple and straightforward. The essential chemical is sodium sulfite, and some alkali is usually present as a buffering chemical. Sodium sulfite may be obtained as a by product of the phenol industry, or it may be manufactured from the reaction between sulfur dioxide, SO_2, and sodium carbonate, Na_2CO_3. The choice is dictated mainly by economic considerations. A plant to produce sodium sulfite liquor from sulfur and soda ash costs about the same over a wide capacity range, so that the cost per pound of sulfite produced goes down as production goes up. At some point it crosses the price of purchased sodium sulfite, and at any greater production, it becomes increasingly cheaper to make sodium sulfite at the pulp mill.

As shown in *Figure 1,* sulfur is burned in conventional equipment, and the sulfur dioxide produced is passed up through an absorption tower, down which soda ash solution passes countercurrently. The reaction apparently proceeds stepwise.

(1) $SO_2 + H_2O \rightarrow H_2SO_3$

(2) $H_2SO_3 + 2\ Na_2\ CO_3 \rightarrow Na_2SO_3 + 2\ NaHCO_3$

(3) $H_2SO_3 + 2\ NaHCO_3 \rightarrow Na_2SO_3 + 2\ H_2O + 2\ CO_2$

(4) $Na_2SO_3 + H_2SO_3 \rightarrow 2\ NaHSO_3$

The first three of these reactions occur quickly and simultaneously. The fourth reaction does not seem to occur to any appreciable extent until all the soda ash has been converted to sulfite. It has been commercial practice to stop the reaction at a point somewhere between reactions (2) and (3), according to the ratio of sulfite to buffer desired, the buffer then being sodium bicarbonate.

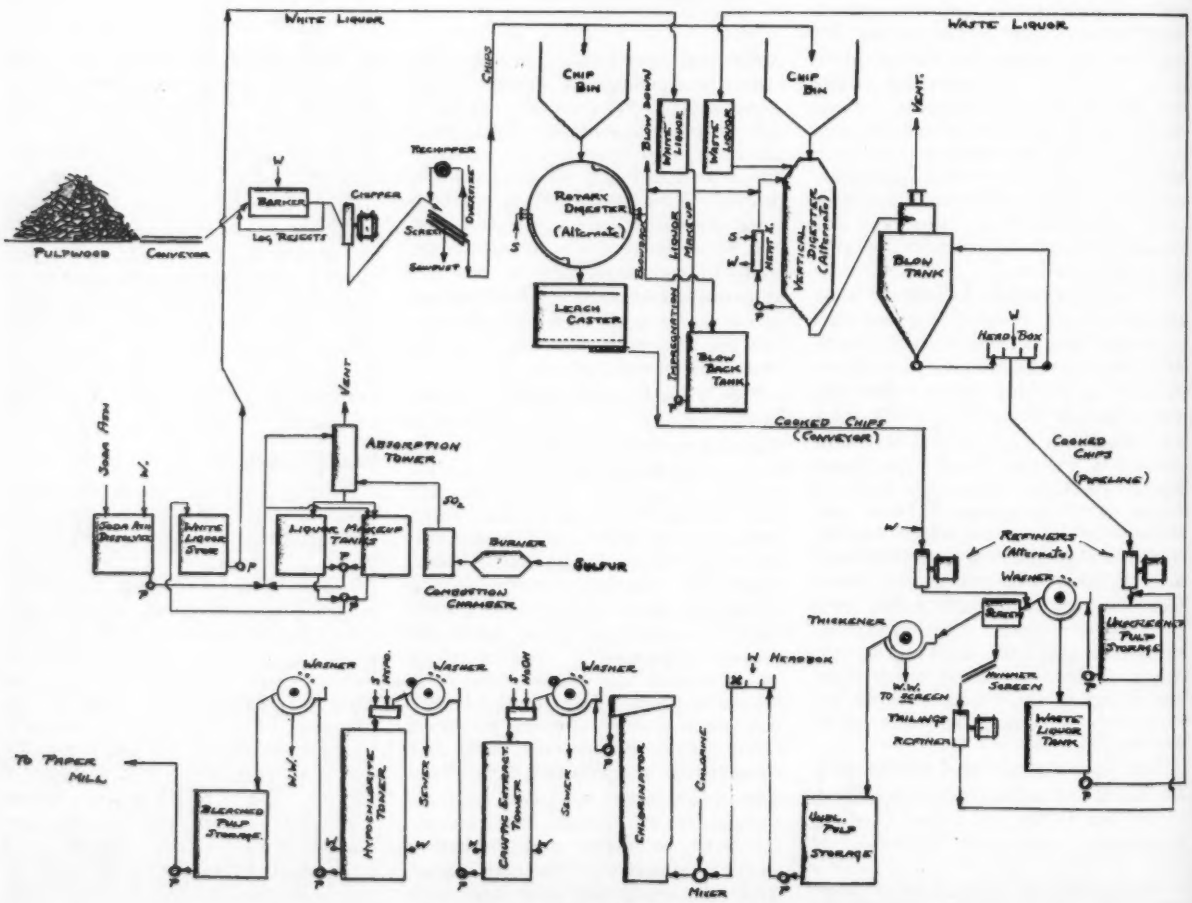

Figure 1—Flow Sheet-Bleached NSSC Pulp

It is perfectly feasible to carry the reaction through to the end of reaction (3), by following the decreasing pH and stopping it at a pH of 7.5 to 7.0. In such case, soda ash must be added to the sulfited liquor for buffering.

In normal operation a batch of soda ash solution is made up to a strength of about 15 to 16 pounds per cubic feet, and steamed to insure complete solution. The solution is pumped to a make-up tank and recirculated through the tower until the desired degree of sulfiting is obtained. Meanwhile another batch may be made up and pumped to the other make-up tank so that changeover may be made rapidly.

The burner gas need not be cooled, in fact hot gas is preferable since it heats the cooking liquor and thereby lowers digester steam requirements. Also, high temperature tends to drive off the carbon dioxide produced in reaction (3), thus enabling a slight reduction in buffering chemical for alkalinity. Burner gas strength is not too important, the only penalty for poor efficiency being the greater gas volume due to excess air, and lowered draft through the tower. If a gas fan is used, it should be placed after the tower, to avoid contact with hot gases.

The liquor is produced at a strength greater than required by the digester, in order to minimize equipment sizes. Tanks should be insulated to prevent undue heat losses.

With regard to buffers, there is no real difference between sodium carbonate and bicarbonate as far as pulp quality is concerned. Since sodium bicarbonate is decomposed into sodium carbonate and carbon dioxide at 100 degrees centigrade, its use as buffer merely means that much more carbon dioxide to relieve. Sodium hydroxide has been used as a buffering agent, with results from several mills somewhat inconclusive and conflicting. It is certainly feasible in case of emergency, since it can be sulfited just as can soda ash.

To make up of ammonia base liquors is quite similar. Liquid ammonia is metered into water solution, which is then sulfited. Depending on the strength desired, it may be necessary to add ammonia during the sulfiting, so as to avoid initial high ammonia concentration and consequent high ammonia loss from the tower.

Cooking

The original method of cooking developed for this process was the so-called *impregnation method.* This is a multi-step method, in which the first step is to steam the chip charge for a short time to displace the air, after which the digester is pumped full of strong liquor containing a large excess of the cooking chemicals. This charge is heated to about 100 to 110 degrees centigrade and held for about one hour to allow the chips to pick up liquor and adsorb chemicals. The excess liquor is then blown back to storage and fortified for use. The digester is then brought up to temperature rapidly and cooked.

This method has several advantages, foremost of which is the excellent penetration of cooking chemicals into the chip, and the uniformity of pulping derived therefrom. Another advantage is that the liquor-wood ratio may be made very low, thus delivering a more concentrated waste liquor if recovery or disposal by burning is desired.

The method also has some disadvantages. The adsorption of the cooking chemicals by the wood is influenced by too many variables not at the control of the operator. For example, very dense wood would not adsorb as much chemical as lighter wood, when the exact opposite is needed. The process is cumbersome and complicated. The use of low liquor ratios requires the use of rotary or tumbling digesters to give uniformity. Time is wasted in the digestion cycle in pumping liquor on and off.

The disadvantages of the impregnation cycle led to trial, and increasing use, of what was originally termed the *basting method,* which is merely a conventional chemical-type cook. The digester is charged with chips, strong liquor containing the desired quantity of chemicals is added, and then the contents are diluted with water or black liquor to give the desired liquor-wood ratio. Cooking then proceeds as in a normal chemical cook. This method is well adapted to vertical, stationary digesters.

TABLE I
Birch N.S.S.C. Pulp

Conditions	Impregnation	Basting
Steaming	Yes	No
Time, minutes	30	
Temperature, °C.	100	
Impregnation	Yes	No
Time, minutes	60	
Temperature, °C.	110	
Pressure, psig.	95	
Na_2SO_3 as Na_2CO_3, o/o basis O.D. Wood	52.7	
Na_2Co_3 as Na_2Co_3, o/o basis O.D. Wood	13.2	
Blowback	Yes	No
Cooking Chemicals		
Na_2SO_3 as Na_2Co_3, o/o basis O.D. Wood	15.5	12.0
Na_2CO_3 as Na_2CO_3, o/o basis O.D. Wood	3.4	4.5
Liquor-Wood Ratio	...	4:1
Digestion		
Maximum Temperature, °C.	165	160
Maximum Pressure, psig.	90	80
Time to Temp., hours	1.0	1.5
Time at Temp., hours	3.0	4.5
End Liquor, gpl. Na_2SO_3	8.8	8.5
Steam	Direct	Indirect
Refining		
Type	Two Stage	Single Stage
Results		
Yield, screened 0.008", o/o basis O.D. wood	72.2	72.5
Lignin, o/o basis O.D. pulp	9.9	9.7

Table I illustrates the cooking of birch wood by both methods. It will be seen that the results are nearly identical. The chemical consumption is somewhat lower in the basting method, and the total time cycle, allowing for pumping on, etc., is about the same, even though the cooking temperature in the basting method was less. These results show that while the two methods give comparable results, the basting method is to be recommended due to greater simplicity, better control, and better adaptability to vertical digesters with their greater capacity and lower cost per ton of pulp.

In the early days of the process, the ratio of sulfite of bicarbonate in the cooking liquor was considered of great importance. High ratios of 7:1 were recommended for bleached pulp, and ratios of 3 or 4:1 were used for unbleached pulp. This ratio is now considered to be a secondary variable, and the actual quantities of the chemicals, based on the wood, are considered to be of primary importance. In mill parlance, the chemical percentages are in terms of sodium carbonate, since this is the actual raw material, and this terminology will be employed here. The sodium bicarbonate or carbonate, while possessing a degree of pulping action, is not particularly selective in this regard, removing too much cellulose as well as lignin, and in this process it is regarded merely

as a buffer, to maintain a slightly alkaline pH by neutralizing the organic acids formed during the cook. The amount necessary for this purpose varies somewhat with the wood species, being in the order of two per cent for aspen, and around four per cent for oaks. Too little carbonae equivalent is bad, since the digester pH will drop to the acid side, causing corrosion of iron equipment, and weakening the pulp through the acid hydrolysis of cellulosic material. Excess or carbonate is not as harmful, although there is evidence to the effect that it will maintain too high a pH and slow the pulping reactions.

Sodium sulfite is the actual pulping chemical. Expressed as carbonate on a basis of the wood, the amounts used vary from 8 or 10 per cent for board pulps to 15 or even 20 per cent for bleachable paper grade pulps. Aspen requires the least chemical, and the dense hardwoods as a group require about the same amount more. Cooking is generally carried down to a residual as low as possible, since the liquor is usually wasted, and 8 to 10 grams per liter of sulfite is common practice in the industry.

Yields vary between 65 and 80 per cent, the higher range being board pulps. There appears to be little advanage in going below about 70 per cent, since yields below this point show little better bleachability or pulp quality. It seems that the pulping reaction, to that point, is fairly selective in removing lignin, whereas beyond it the removal of cellulosic material is accelerated, and little net gain results. Little value is obtained in going over 80 per cent, since that would bring about too much refiner damage, and result in higher power cost and poor quality.

Cooking cycles vary considerably throughout the industry. One factor appears to be whether the mill has a sulfite or kraft background. If penetration is secured, the temperature can be raised rapidly, and, especially in board mills, this rate is determined mainly by the steam capacity. Cooking temperature varies from 150 to 175 degrees centigrade. The higher temperatures shorten the cooking cycle considerably, at the cost of a slightly lower yield for the same chemical consumption. The 160 to 170 degrees centigrade range appears to be optimum.

There are several other points that bear mentioning here. First, penetration, while not perhaps as important as in acid sulfite, is a definite factor, especially for bleachable pulps. Incomplete penetration leads to brown centers which are hard to defiber, and are difficult to bleach. Particularly with dense hardwoods, it is desirable to go to a small chip, one half inch or less, and to see that the chip screens are taking out the oversize chips. Due to the short fiber length, of hardwoods, the strength of the pulp is not affected by cutting short chips. For bleaching purposes, therefore, short chips and the maximum available temperature rise period are desirable.

Secondly, the digester should be relieved well, to eliminate carbon dioxide and other volatile acids produced by the cook. If not relieved, these will lower digester pH, with the aforementioned bad results. Automatic relief controls which maintain the saturated steam pressure-temperature relationship are recommended.

Ammonium base neutral sulfite has been investigated to a large degree, and has been and is used commercially. It has been claimed that better pulping may be expected with this case, since the smaller ammonium ion penetrates better. This is a logical argument, although commercial use has not shown any significant difference in this respect. Perhaps the greatest difficulty encountered is the fact that, with ammonium base, the buffer is ammonium hydroxide, which is volatile. Thus, if one relieves the digester, the buffer escapes, and if one does not relieve, the organic acids and carbon dioxide neutralize the buffer, thus giving low pH in either case. In addition, ammonium hydroxide is a pulping agent, but is not selective, and tends to lower yields and/or to lower strength. Experiments are now underway to inject ammonia during the progress of the cook to eliminate loss, and, if successful, the ammonium base may become more prominent.

Refining

The primary purpose of the refining step is to separate the softened, cooked chips into individual fibers with as little damage to the fiber as possible. This purpose should be accomplished with the lowest feasible power consumption and cost. At the present time, the industry is using disk mills almost exclusively, and their performance has been very acceptable. There is always a continuing search for new refiners which will do a better job a lower cost, but as of this moment nothing else is in operation. In the infancy of the process, ball or rod mills were used for refining, but they suffered from the defects of cumbersomeness, low efficiency with respect to power expended on the fiber, and too much beating action.

Depending on the method of handling the cooked chips after the digester, refining may be done hot or cold. Hot refining is a development which seems destined to increase in use. The chips are refined in the hot waste liquor, without washing prior to the refiner. The big advantage is that the hot chip is softer, thus permitting easier fiberizing, a lower power usage, better uniformiy, and less mechanical damage to the fiber. In addition the recovery of waste liquor is enhanced. Displacement washing of the chips, as in a leach caster, does not permit much diffusion of liquor from the chip, and the amount of waste liquor solids trapped in the chip is appreciable. If, as shown in *Figure 1,* the hot refined pulp is washed on a vacuum washer, (preferably two stages) the recovery of waste liquor solids is much better.

There is some evidence to support the fact that corrosion becomes more of a problem in hot refining, and the use of high nickel iron or stainless trim is indicated. Another possible disadvantage, which has been indicatd but not proven, is that irregularities may occur in mill operation which cause the chips to be held in hot liquor for 18 to 24 hours before refining. One mill claims that this softens the pulp so much that they can not maintain board strength. In spite of these disadvantages, the hot refining method appears to be the logical, preferred system.

There is still considerable argument over the use of single or multistage refining. Two stages were used extensively with disk mills for sometime. Two stage operation, however, is difficult to control. Often one refiner does almost no work while the other carries the load. Then, again, if the refining load is evently split, the fiber which has been produced in the first stage is subjected to unnecessary work in the second stage which damages and slows it so that subsequent screening and washing become difficult. True, single stage refining is often satisfactory for board pulp, but the amount of shives and chunks produced is prohibitive for fine pulp, and too big a loss if screened out. The best modern practice, then, is the use of a single refining stage, followed by screens, with a small refiner to work on the screen rejects and return them to the screens. Thus, little unnecessary work is done on good fiber, and the total power cost is lower, and rejects are almost nil.

Power consumption runs from 15 to 20 horsepower days per ton, the lower value being for coarse board pulp. The refining considered in this section is the pulp producing refining. The pulp preparation for papermaking purposes is handled in conventional beaters, jordans, and the like, and will not be considered here.

Bleaching

Unbleached semichemical pulp, even

when cooked for bleaching, contains much more lignin than normal chemical pulps. The problem of bleaching can therefore be attacked in wo different ways. One can attemp to bleach the pulp to a higher brightness while removing as little lignin as possible, or one can remove the lignin in so far as practicable, and then bleach the remaining cellulosic material. The two points of attack produce entirely different end products, and are worthy of separate consideration.

The first method is exemplified by single stage hypochlorite or peroxide bleaching. Typical hypochlorite bleaching conditions are shown in *Table II*. Both hypochlorite and peroxide bleaches are limited to a medium brightness range of perhaps 55 to 70. Yield loss is quite low, and strength properties are little changed by the bleaching step. There is a tendency for hypochlorite to cause slight decreases in strength, while peroxide may show either a slight increase or decrease in some strength characteristics. This type of bleaching, then, alters the basic nature of the pulp very little.

The second method of bleaching is really pulp purification followed by bleaching. If the unbleached pulp in chlorinated, much of the lignin is converted to products soluble in water, and some to products soluble in dilute alkaline solution. Thus, a chlorination stage followed by a caustic extraction stage removes much of the bleach consuming materials from the pulp, so that a small amount of hypochlorite suffices to produce a high brightness product. The effectiveness of the caustic extraction stage may be seen by comparing the two and three stage bleaches. Omission of the caustic extraction raises the hypochlorite consumption to the point where total chemical requirement is higher in the two-stage system, while the final brightness is not as high.

The removal of lingnin apparently frees the hemicellulosic materials in the pulp, and their contribution to pulp strength causes very appreciable gain in strength on bleaching.

Thus, comparing the two methods, we find that multi-stage bleaching gives a much whiter and stronger pulp, at the cost of increased plant investment and appreciably lower field.

Bleaching techniques are still undergoing study. It has been found feasible to bleach mixtures of N.S.S.C. and chemical pulps together with little loss in efficiency. The high chlorine requirement of N.S.S.C. pulp has been a drawback in the past. Since chlorination is, in effect, a more selective continuation of the cooking process, it is necessary to study each instance to determine the best breakpoint between purification by cooking and purification by bleaching.

Recovery

The recovery and reuse of N.S.S.C. waste liquor has been investigated ever since the early days of the process. Early attemps were not very successful, and as a result, the development of the process was somewhat hindered, and the related full chemical, neutral sulfite process, with its greater chemical consumption, was almost entirely abandoned.

The N.S.S.C. process developed in spite of this handicap, but recently several important factors have spurred renewed activity in the field of waste liquor recovery. The first factor is the rapid increase in anti-stream pollution legislation, the second is the sulfur shortage, and a third reason has been covered in the discussion of cost factors.

Stream pollution is not as severe in the semichemical process as it is in the sulfite process. For an equal tonnage of unbleached pulp, the sulfite process puts about three times as much waste liquor solids into the river. Thus, if a sulfite mill were to be replaced by a semichemical mill, the pollution load would be considerably lightened. More often, though, the neutral sulfite process is an adjunct to the existing facilities, so that the total pollution load is increased.

The sulfur shortage came more or less as a surprise to the industry. Here again the semichemical process uses less sulfur than is consumed in the manufacture of an equal quantity of sulfite pulp. The same argument as given above applies here in that some mills have postponed construction and expansion plans because of the unavailability of the sulfur which would be required.

Every system of recovery which has been proposed to date starts with the separation of the waste liquor from the pulp, its concentration by multi-effect evaporators to about 50 per cent solids, and further concentration in a cascade, or similar direct contact, evaporator to about 70 per cent solids. This concentrated liquor is then introduced to a furnace and burned. The resulting smelt or ash contains sodium sulfide and sodium carbonate. Up to this point the system is identical with a kraft recovery system. It is not as attractive economically as the kraft system for several reasons. First, the higher yield of pulp means a lower concentration of solids in the waste liquor, and therefore a greater load on the evaporators and a greater steam consumption by them. Second, the greater ratio of sulfur to soda in the cooking liquor causes a much higher stack loss of sulfur in the furnace.

Most of the recovery systems which have been proposed come to grief on the next step. The sodium sulfide (Na_2S) must be oxidized to sodium sulfite (Na_2SO_3). It is relatively simple to stop the oxidation at thiosulfate ($Na_2S_2O_3$), and it is also easy to go up to the normal sulfate (Na_2SO_4), but sodium sulfite is difficult to obtain. The normal sulfate has no value in pulping, and thiosulfate, while it may have some slight pulping action, is generally considered injurious to yield and quality.

The methods which have been or are now under consideration may be divided roughly into four clases. Of these, three may be considered as direct recovery processes. First are the controlled oxidation methods, where the smelt is treated with air, with or without catalysts. Several processes

TABLE II
Aspen N.S.S.C. Bleaching

Conditions	Single Stage	Two Stage	Three Stage
Chlorination			
Cl_2 added, %		12.7	12.7
Temperature, %		70	70
Consistency, %		3.0	3.0
Time, minutes		30	30
Final pH		1.65	1.65
		Wash	Wash
Caustic Extraction			
NaOH Added, %			2.0
Consistency, %			12.0
Temperature, °F.			120
Time, minutes			60
Final pH			10.7
			Wash
Hypochlorite			
Cl_2 Added as NaOCl, %	10.0	3.3	1.0
NaOH for pH, control, %	1.5	1.0	0.3
Consistency, %	12.0	12.0	12.0
Temperature, °F	100	100	95
Time, minutes	180	30	120
Minimum pH	10.0	10.0	10.0
	Wash	Wash	Wash
Results			
G.E. Brightness, %	64.9	79.5	83.6
Yield, %	90.7	86.7	84.5

have claimed that economically feasible conversion to sulfite can be obtained by this operation, and one such process is on the market today.

Second are the carbonation methods, which treat the sulfide-carbonate solution with flue gas or carbon dioxide, to give sodium carbonate and hydrogen sulfide, which is then burned to sulfur dioxide and reused. In this group may also be included the old Leblanc process, where calcium carbonate is the carbonating agent.

The third and most recent method involves the use of ion exchange resins to remove the sulfide ions, which are then released as hydrogen sulfide and burned to recover sulfur dioxide. These three classes are all undergoing, pilot plant development at this time, and we have heard that several mills are about ready for commercial installations of their methods.

The fourth class of recovery methods is where the neutral sulfite waste liquors can be combined with the black liquor from the kraft process. This is a highly satisfactory procedure for the neutral sulfite liquor carries an excess of sulfur over soda, which is the correct division for an efficient kraft recovery unit. The only drawback to this scheme is that the N.S.S.C. plant is limited to about one quarter of the production of the kraft mill.

Reviewing the whole situation, soda-base recovery in conjunction with a kraft mill has been proven feasible, and the idea is rapidly taking hold among the large kraft mills in the South. The direct recovery methods have not yet been commercially proven, but the next year or so should furnish more data regarding several of the methods.

The big argument for recovery is the removal of stream pollution troubles. The economic side, while not as attractive as in the kraft process, is not too discouraging, especially in these days of rising chemical costs. Most of the methods examined by the writer would show capital expenditures not too different from the sulfate recovery units.

Turning to the ammonia bases, we find that evaporation and burning of the liquor is quite feasible, and recovery of sulfur can be made in the order of 70 to 80 per cent.

Pulp Qualities

Unbleached, board type N.S.S.C. pulps are rather dark, rarely with General Electric brightness over 40, shivy, and stiff. They are quite difficult to beat, requiring considerable time and power. Their most desirable quality is their stiffness, which makes possible the manufacture of corrugating medium having a high crush test, and most all of the unbleached N.S.S.C. pulp made is used for this purpose. They have mediocre burst, low tear, and, usually, poor folding endurance, so that they are not suitable for liners and most other flat boards.

Unbleached paper type N.S.S.C. pulps suffer from the same defects as the board types, though not in as great degree. They are not made and used to any appreciable extent, but could replace other hardwood pulps, or perhaps even unbleached sulfite in part, in furnishes where cleanliness and brightness are not too important.

Single stage bleached N.S.S.C. pulps can replace unbleached sulfite, bleached soda, or semi-bleached kraft in many applications, such as milk bottle, coated board, ground wood printing, and similar furnishes. The semi-bleached pulp is fairly clean, has a creamy tint, and works easier than the unbleached. It does not have the strength to be used as all, or the major part, of a furnish.

Full bleached N.S.S.C. pulp has properties quite different from the foregoing, and is really in a class by itself. It can be obtained in brightnesses of 85 General Electric or better, it beats with extreme rapidity, retains filler well, and its strength properties are excellent. A good, bleached N.S.S.C. pulp will approach a good northern kraft pulp in all strength properties except tear, and the tear will be equal to or better than most eastern sulfite pulps. The bleached pulp is characteristically hard and tinny, and if clean should be excellent for bond. The ease with which it hydrates makes it ideal for glassine, and its strength properties at the glassine stage are superior to those of most pulps we have tested.

On an experimental basis, it has been incorporated successfully in almost every grade of paper known, with the exception of toilet and facial tissue. It sems to blend exceptionally well with any other type of pulp. Bleached N.S.S.C. has, in the past, had several drawbacks which have hindered its wider use. The first of these is dirt, which has been greatly reduced as more "know-how" has been accumulated.

A second reason is the fact that it is a short fbered pulp, and so has a low wet-web strength (before the sheet has been dried). This can be overcome by proper design of the paper machine by the use of pick-up felts to eliminate unsupported draws, etc.

A third reason is the problem of brightness reversion. Bleached N.S.S.C. will revert more than a bleached sulfite of equal brightness, because of the greater hemicellulose content. However, if the problems of dirt and machine operation are solved, the color reversion alone is not sufficient to rule out the pulp.

Summing up the pulp characteristics, we find that the N.S.S.C. process gives us, from the short fibered hardwoods, pulps that are of value and strength in their own right. They need not be mere fillers, thrown in at a sacrifice in quality in order to utilize the wood, but can equal or surpass the long fibered pulps which they replace.

Other Semichemical Processes

A search of the literature reveals that almost every chemical compound has been tried for semichemical pulping. Even water has an effect, as witness the early work on steamed groundwood and recent work on steam and water cooked chips at the Firest Products Laboratory. There are a number of processes now current which are worth mention.

(1) *Semichemical sulfite.* High yield sulfite is in commercial operation. Considerable work has been done on this process at the University of Maine. The commercial yield range is generally from 50 to 60 per cent, and the pulp is refined in attrition mills or Curlators. The chief advantages are lower steam and sulfur usage. Power usage for refining is low (three horsepower days per ton) since the chips are highly softened. There is no great loss in strength.

(2) *Semichemical sulfate.* The use of less chemical and shorter cooking time give a dark chip which can be refined in attrition mills for board pulp. Power costs compare with N.S.S.C, but the pulp is very difficult to bleach, and is not as strong as regular kraft, or as good as N.S.S.C. for nine point.

(3) *Asplund and derivatives.* These methods use reaction chambers through which the pulp moves continuously, to a refiner working at digester temperature and pressure. They employ high temperatures and pressures for rapid reaction, and may use steam, soda, kraft, or neutral sulfite liquor. The advantages lie in lower power usage due to high temperature refining, but the short cook causes the product to be used mostly for insulating felt, wallboard, etc.

(4) *Chemi-graundwood.* This process was developed to a commercial scale at the New York State College of Forestry, although its antecedents go far back in the literature. Essentially it consists of a mild neutral sulfite cook on the hardwood log, which is then made into pulp on the grinder. The pulp can be produced with greater strength and lower power consumption than coniferous groundwood, and may be bleached in a single stage to 65 to 75 General Electric brightness.

(5) *Cold caustic.* Originated at the

Forest Products Laboratory, this process treats chips with caustic soda solutions of 1 to 10 per cent concentration at atmospheric pressure over fairly long periods. The chips are refined in attrition mills. The resulting pulp is quite light in color, coarse, and is suitable for wallboard or, in admixture with N.S.S.C. pulp, for nine point.

Economics

The cost of an N.S.S.C pulp mill should be quite similar to that of a sulfite mill of equal capacity. Items of increased cost would be screening and washing, due to slower stock, and refining. On the other hand, digester capacity could be lower, since production per digester is higher.

Unbleached, board type N.S.S.C. pulp can be produced below the cost of unbleached sulfite pulp. The higher cost of chemicals and power for refining is well counterbalanced by the higher yield of pulp and the lower cost of wood.

Bleaching costs, particularly for the multistage method, are high, and make the cost of bleached N.S.S.C. more in the range of conventional bleached chemical costs.

Conclusion

It is believed, for the reasons explained, that use of the N.S.S.C. process will be extended materially in the near future. It can be said now that pulp resulting from it is cheaper than unbleached sulfite or kraft and bleached N.S.S.C. of about the same cost as bleached sulfite. The advantages of the process are cheaper wood, higher yield and lower steam costs. The disadvantages are a higher chemical cost and higher power cost.

Neutral Sulfite Semichemical Pulping

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Purpose of Semichemical Pulping

The main purpose of semichemical pulping, like that of any pulping process, is to separate the fibers in wood or other fibrous material, so that they can be recombined in products that are more useful than the original material, such as papers and boards. Semichemical pulping, to which the United States Forest Products Laboratory has devoted much attention in the past 25 years, is distinguished from the more common pulping methods in that its aim is to produce pulps that approach groundwood pulp in yield, yet resemble chemical pulps in properties. The main idea behind developing this process was to produce a low-cost pulp from little-used but available woods, like the hardwoods.

Definition of Semichemical Pulping

Semichemical pulping can be defined as a two-stage process involving (1) mild treatment to remove part of the fiber-bonding lignocellulose or otherwise to affect the fiber bond and (2) mechanical action on the treated fiber aggregate to complete the fiber separation. The importance of each of these two stages for the successful employment of the process cannot be overemphasized.

The operation of producing fibers in a high yield by a two-stage process can be performed over a wide range of conditions. If the definition is interpreted broadly, a semichemical pulping process could involve, on the one hand, grinding of steamed or chemically treated wood bolts, as in the chemi-groundwood process, or treatment of chips at high steam pressure, as in the Masonite and Asplund processes. When chips are treated at high steam pressure, some chemical action actually ensues. On the other end of the scale, the so-called high-yield sulfite and sulfate processes, in which the chips are not completely defibered during the blowing of the digesters, also can be thought of as semichemical processes. Semichemical pulping, however, is usually understood to occupy a position between these two extremes. In other words, it involves pulping wood chips to a yield in the range of 65 to 85 per cent with a chemical pulping agent other than that formed from the wood —that is, other than the acids resulting from hydrolysis of the wood with steam or water.

History of Semichemical Pulping

The idea of semichemical pulping is not new, even though the practice is relatively so, and the idea of making a pulp with a minimum loss of the major wood components, lignin and holocellulose, is nearly as old as the idea of semichemical pulping. In 1874, Mitscherlich, who is identified historically with the sulfite process, patented a process for softening chips with sulfurous acid or a sulfite and disintegrating the softened chips by grinding. Other means or processes associated with the early days of semichemical pulping may be found in patents and include the use of sodium bisulfite, as reported by Kellner in 1885; the use of sulfur dioxide in combination with sulfite liquor or sodium chloride, as proposed by Mache-Wiig in 1914; and a number of others, as listed in an excellent review by Rue *(2)* in 1925. Most of the early processes were discussed in Rue's paper. In this review, the limited means available for disintegrating the cooked chips were stressed. The importance of satisfactory disintegration still holds today and is probably the part of the process that needs the most improvement.

The early attempts at disintegrating the softened or partially pulped chips

* Maintained at Madison, Wis., in cooperation with the University of Wisconsin.

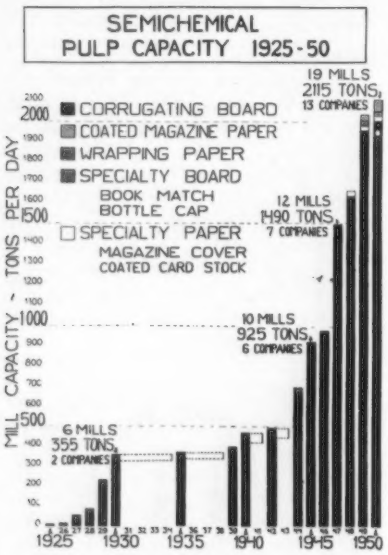

Figure 1—Capacity for production of semichemical pulp from 1925 to 1950.

involved the use of edge-runners or kollergangs, swing-hammer shredders, rod mills, and disk attrition mills. Rue's article predicted the suitability of the disk mill with two plates, one or both rotating in a vertical plane. This type of equipment is used almost universally now in semichemical pulping.

The first commercial production of semichemical pulp did not occur until 1925 when the Southern Extract Company in Knoxville, Tennessee, made semichemical pulp from chestnut chips with the tannin extracted and converted this pulp to corrugating board. In Tennessee and eastward into Virginia, the chestnut trees were killed by a blight that left standing dead trees. Chestnut has a high content of tannin and, for many years, has furnished a large portion of the domestic tannin supply. The dead chestnut wood, up to 1925, was processed mainly for tannin and the extracted chips were burned. It was suggested that the by-product chips might have value for their fiber content and they did prove suitable for use in semichemical pulping. The pulp was converted into corrugating board, and that was the start of a large semichemical corrugating-board industry. The process was adapted from a development at the United States Forests Products Laboratory in the early 1920's and was patented by Rue, Wells, and Rawling in 1932 *(3)*.

The production of semichemical pulp has risen considerably since 1925. In *Figure 1*, the history of semichemical-pulping capacity is shown from the initial year of 1925 to 1950. Increase in productive capacity was slow up to 1940, when six mills had a capacity of about 400 tons per day. By early 1950, there were 19 mills with a capacity of about 2,000 tons per day. At the present time, the productive capacity is over 2,300 tons per day. The solid portions of the bars in *Figure 1* represent corrugating board. Most of the early production was used for corrugating board and most of today's production is also used for that product. The cross-hatched portions in *Figure 1* indicate a trend for increased production of other products. It is in this field that advances in semichemical pulping will probably be made in the next years, that is, in producing pulps for white papers, although semichemical pulp is admirably suited for making corrugated board.

Semichemical Pulping Procedures and Equipment

The over-all procedure for semichemical pulping can be divided into (a) liquor preparation, (b) partial cooking with the chemical, and (c) fiberization or disintegration of the cooked chips into well-separated fibers.

Semichemical pulping can be carried on with any of the common pulping agents. Acid sulfite, soda, and kraft (sulfate) liquors can be used. Sodium sulfite in a neutral solution, a cooking agent that has been less commonly used in the past, can also be used. In 1880, Cross found that sodium sulfite is an excellent pulping agent but, for several reasons, sodium sulfite did not find its true place in the pulp industry until now. One reason is that large amounts of chemical at high concentrations and high temperatures are needed, because the pulping is conducted in a neutral solution where the action is rather slow. The other is that, because of the high requirement of soda base, recovery is essential and no recovery method has been developed as yet that has proven to be generally useable. The process of using sodium sulfite for making full chemical pulp was tried in this country in the 1920's, and one mill survived until the early 1940's, but, as far as is known, the process is not practiced at the present time. The sodium sulfite type of cooking agent is, however, excellently suited for semichemical pulping and it is the one that is used the most in the industry.

Kraft pulping liquor is also used to a relatively small extent. For preparation of this liquor, obviously, customary kraft-pulp-mill practice can be used. Most of the kraft semichemical mills are associated with regular kraft mills.

For the neutral sodium sulfite process, the sodium sulfite, which is the basic pulping chemical, can be either purchased as a byproduct material, from phenol manufacturers for example, or it can be made directly by treating soda ash with sulfur dioxide to form sodium sulfite and sodium bicarbonate. It is desirable to have a certain amount of sodium bicarbonate (or carbonate) present in order to maintain the pulping solution somewhere near the neutral point. This is done mainly to avoid corrosion of the iron equipment that is generally used for neutral sulfite semichemical pulping.

In *Figure 2*, a flow sheet is shown for semichemical pulping, including the liquor preparation. In the dissolving tank, the soda ash, steam, and water are added, and the soda ash solution is made up to the proper concentration. The solution is then pumped to either one of two sulfiting tanks. The operation of making the liquor is a batch process. The soda ash solution is circulated through the sulfiting tower and sulfur dioxide is introduced at the point indicated on the flow sheet. The process is one of absorption. After the solution in the active sulfiting tower reaches the right concentration, which is determined by analysis for its so-

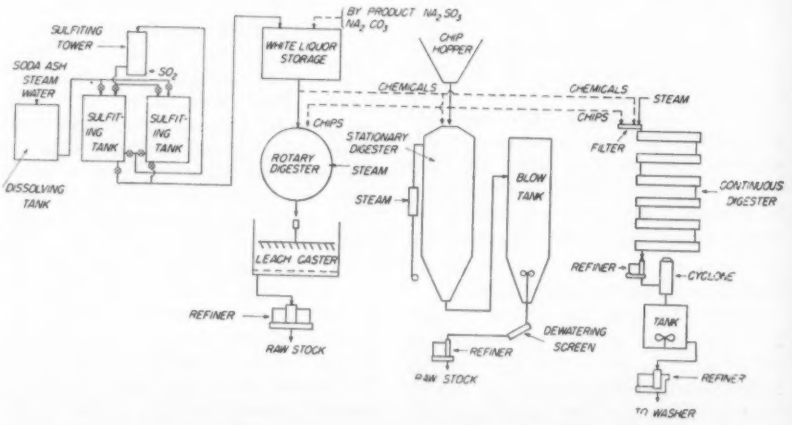

Figure 2—Simplified flow sheets of typical semichemical pulping processes.

dium sulfite content, it is pumped to the storage tank. Sulfiting then starts on the soda ash solution that has been pumped to the second sulfiting tank in the meantime. This solution is brought up to the proper concentration and the storage tank kept at the desired level.

The cooking operation is conducted according to one of two procedures, with several kinds of equipment. One procedure is a batch process, equipment for which is similar to that for kraft or sulfite pulping. This set-up is shown in *Figure 2.* In several instances, sulfite and kraft digesters have been converted for semichemical pulping. The charging of the chips and liquor is as usual and the heating can be done by circulation through a heater. The chips can be blown into a blow tank or blow pit fitted with a leach caster. A leach caster is a tank with a false bottom for draining off the cooking liquor. It has a horizontal revolving arm equipped with rakes that scrape the chips from the center to the outside, where they fall into an inverted cone opening at one point near the periphery. The raking device lowers itself automatically at a rate controlled for the production desired. The chips fall through the opening onto a conveyor for ultimate feeding to the fiberizers.

Another common set-up usually includes the leach caster but uses a rotary digester for cooking, as is also shown in *Figure 2.* The digesters are of the spherical type of cast-iron construction and commonly have diameters of 14, 15, or 16 feet and pulp capacities of four to seven tons.

The second procedure is a continuous operation employing reaction tubes equipped with conveyors, as also shown in *Figure 2.* The chips are fed from a hopper into a screw feeder, which compresses them to form the seal against the high steam pressures, about 175 pounds per square inch, used for cooking. Steam and chemicals are fed into the feeder, as indicated in *Figure 2,* and the chips and chemicals go back and forth in the tubes as the pulping reactions proceed. The reacted material at the end of the last tube is generally fed under pressure to a single-disk attrition mill and the pulp is discharged into a cyclone to relieve the pressure.

The equipment described is that used for the partial pulping of the wood chips. In this pulping, a part of the lignocellulose bonding material is removed and the chips are softened so that the fibers can be separated mechanically in more or less integral form. Although rod mills were used for fiberizing in the early days of semichemical pulping, attrition mills of the vertical disk type*(1)* are almost universally used at the present time. In the disk fiberizers, the chips are generally fed into a vertical chamber and enter the action zone at the center of one of the disks. The chips are then forced by centrifugal force out between the two disks and the pulp is collected at the bottom of the housing surrounding the disks. The rate of feed, the plate clearance, the temperature, and the moisture content (consistence) of the stock at the point of fiberizing are controlled. The abrasive action of the disks also can be altered by the pattern on their surface.

Neutral Sulfite Semichemical Pulping Conditions

The two liquors that are used mainly for semichemical pulping are sulfate and neutral sulfite, which is sodium sulfite buffered with either sodium bicarbonate or sodium carbonate. In instances where mills purchase byproduct sodium sulfite, the solution is buffered with soda ash rather than with sodium bicarbonate because the soda ash is cheaper. In neutral sulfite pulping, two general types of pulp are made. One is board pulp and the other is a pulp for bleaching. The board pulp is by far the most commonly made. There are only two or three mills that are making pulp for bleaching at the present time, but more are under construction.

Board Pulp. The yield for board pulp ranges from 70 to 80 per cent. The sodium sulfite requirement is in the range of 8 to 14 per cent, based on the weight of the wood. This is an appreciable amount of chemical in comparison with kraft pulping in which the total active alkali, or sodium oxide, is only about 15 per cent based on the wood. To the sodium sulfite requirement must be added the sodium bicarbonate requirement of four to five per cent, on a wood basis. These values for sodium sulfite and sodium bicarbonate can be converted into terms of the basic chemicals to give average figures for semichemical board pulp of 59 pounds of sulfur and 262 pounds of soda ash for the production of one ton of air-dry pulp. In comparison, the requirements for one ton of air-dry sulfite pulp are about 200 to 250 pounds of sulfur and 300 pounds of limestone. The concentration of the chemicals in the cooking solution will depend on the chemical needed for the desired degree of pulping, the moisture content of the wood, and the ratio of liquor to wood used. In rotary digesters, for example, the starting ratio may be 2.5 to 1, and the sodium sulfite concentration may be 60 to 80 grams per liter.

Cooking temperatures, because of the neutral solution, are rather high and range commonly from 150 to 175 degrees Centigrade in batch pulping procedures; a common temperature is 170 degrees Centigrade. This is also a common temperature in kraft pulping, but it is higher than the 130 to 150 degrees Centigrade used for sulfite pulping. In continuous semichemical pulping, the temperature may be 1880 to 190 degrees Centigrade.

Cooking times are somewhat shorter for semichemical pulping than for full chemical pulping, because less lignin is removed, and range from one to four hours for the batch procedure, depending on the temperature used. This is the general range for sulfate pulping but, of course, it is much shorter than the 7 to 16 hours for full acid sulfite pulping. In the continuous pulping procedure at high temperature and pressure, the cooking time is of the order of 2 to 20 minutes.

The energy required to fiberize the semichemically cooked chips for board pulp is in the range of 12 to 18 horsepower-days per ton of air-dry pulp.

Bleachable Pulp. The chemical requirements and other conditions for producing bleachable semichemical pulp are somewhat more severe than those for board pulp. This is because a greater amount of lignin must be removed. The following conditions are generally observed: (1) The yield of unbleached pulp is in the range of 68 to 83 per cent. (2) The sodium sulfite requirement ranges from 15 to 20 per cent based on the wood. (3) The average basic chemical requirements are 115 pounds of sulfur and 460 pounds of soda ash per ton of air-dry pulp. (4) The cooking temperatures are 160 to 175 degrees Centigrade and the cooking times are three to eight hours. (5) The energy for fiberizing is in the range of 10 to 15 horsepower-days per ton of air-dry pulp.

Sulfate Semichemical Pulping Conditions

The pulp yields in sulfate semichemical pulping are in the range of 70 to 75 per cent. The amount of chemical is one-third to one-half of that used in full sulfate pulping, or three to seven per cent of active alkali (sodium oxide), based on the wood. In the batch process, the cooking temperatures are 160 to 170 degrees Centigrade and the times are 0.5 to 3 hours. In the continuous process, the temperature is 180 to 190 degrees Centigrade and the times are two to ten minutes.

Theory and Mechanism of Semichemical Pulping

Little is known about the theory and mechanism of semichemical pulping. Presumably, when semichemical pulp-

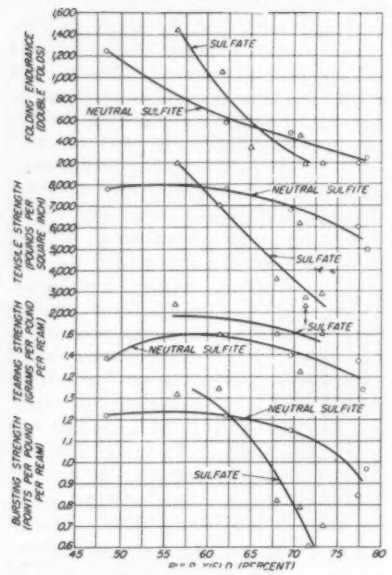
FOLDING ENDURANCE (DOUBLE FOLDS)
TENSILE STRENGTH (POUNDS PER SQUARE INCH)
TEARING STRENGTH (GRAMS PER POUND PER REAM)
BURSTING STRENGTH (POINTS PER POUND PER REAM)
SULFATE
NEUTRAL SULFITE
PULP YIELD (PERCENT)

Figure 3—Relation of strength properties of jack pine neutral sulfite and sulfate semichemical pulps to yield of pulp.

ing is done with sodium sulfite, some of the theory associated with acid sulfite will apply. This would indicate some sort of sulfonation, perhaps formation of a sodium lignosulfonate. It is known, of course, that, under mild hydrolysis, acetic acid or, in the presence of sodium ions, sodium acetate will be formed from the acetyl groups present in wood.

Pulping Variables in Semichemical Pulping

One of the major variables in pulping is the wood itself. Its density, chemical composition, color, content of bark and knots, decay content, and fiber characteristics influence its pulping by the semichemical process as well as other processes. Hardwoods are generally used for semichemical pulping; softwoods are used infrequently. There are seveal reasons, such as:

1. Softwoods make very satisfactory pulps by one or the other conventional processes, so there is not much point in cooking them semichemically except for the advantage of a high yield. Hardwoods, on the other hand, have not always produced satisfactory pulps when pulped by conventional methods. The hardwoods are given unique properties when pulped by semichemical methods, so that there is now a more definite place for them in pulp manufacture than there was before semichemical pulping was developed.

2. Hardwoods give semichemical pulps that are much stronger in relation to their fiber length than are softwood semichemical pulps. In other words, relatively better pulps are obtained from hardwoods by the semichemical process than from softwoods.

3. Because softwoods generally are more difficult to pulp and have longer fibers than hardwoods, they require larger amount of chemical and fiberizing energy to produce a pulp.

Among the hardwoods, the species of wood also plays an important part in the quality of semichemical pulp that can be produced. For example, dense woods with a high content of lignin and of water-soluble materials, like many oaks, may have a low chemical requirement but give pulps with a high lignin content and low strength. Low-density woods with a low lignin content, like the poplar family, tend to have intermediate chemical requirements and give pulps with good strength as well as a low lignin content. High-density woods with an intermediate lignin content, like birches and gums, often have an intermediate chemical requirement and give pulps with excellent strength for semichemical pulp and an intermediate lignin content. Softwoods have high chemical requirements and may give pulps with relatively poor strength and high lignin content. This is a very broad classification with respect to the effect of species on quality of semichemical pulp. Each species, however, seems to bring up a new problem as far as its usage is concerned. This means that it is difficult to predict how different or unknown species will react semichemically. It almost seems necessary to conduct trials in each case.

A more or less obvious property of wood that affects a semichemical pulp property is its color or brightness. A light-colored wood, like poplar or birch, gives a light-colored pulp of 45 to 50 per cent brightness. Dark oak gives a dark semichemical pulp.

The bark on wood also has an important effect in semichemical pulping. For pulps intended for products where appearance is not of prime importance, such as corrugating boards, the bark of certain species, like hickory, may be left on the wood with little effect on pulp quality. A reduction in strength is realized, on the other hand, if poplar bark is not removed. In any case, a mill will need to balance reduction in quality against the cost of barking. If the highest quality is wanted, then the wood will have to be barked. Of course, in making pulp for bleaching, bark will be necessarily removed.

The major variables of the chemical stage of semichemical pulping include, naturally, those involved in any chemical reaction, such as chemical concentration, time, and temperature. Other variables in semichemical pulping are the chemical reagent, the buffering agent in neutral sulfite semichemical pulping, the ratio of chemical to wood, the moisture content of the wood, the recycling of spent liquor, and, possibly, the prehydrolysis of the wood.

As temperature increases, the reactions proceed at a faster rate, and, like many other organic chemical reactions, the rate is approximately doubled for every 10 degrees Centigrade rise in temperature. The reaction rate is also increased with an increase in the concentration of the cooking liquor. In semichemical pulping, pressure is a minor factor, in contrast with sulfite pulping, because, except for the pressure of the steam, the only excess pressure is from a certain amount of carbon dioxide released from the wood reactions or from sodium bicarbonate in neutral sulfite pulping. This carbon dioxide can be removed without affecting the chemical reaction except that its presence keeps the cooking liquor headed toward the acidic rather than the alkaline direction. Pulp brightness tends to be darker when carbon dioxide is released.

The amount of chemical used depends on the degree of pulping desired; thus, a board pulp requires 8 to 14 pounds of sodium sulfite, on a wood basis, and a bleachable pulp 15 to 20 pounds. All the properties of the pulps can be traced to the extent or degrees of pulping. When a large amount of chemical is used, the pulp yield is low, and the properties of the pulp will reflect the low yield. Some relations between pulp yield and strength are

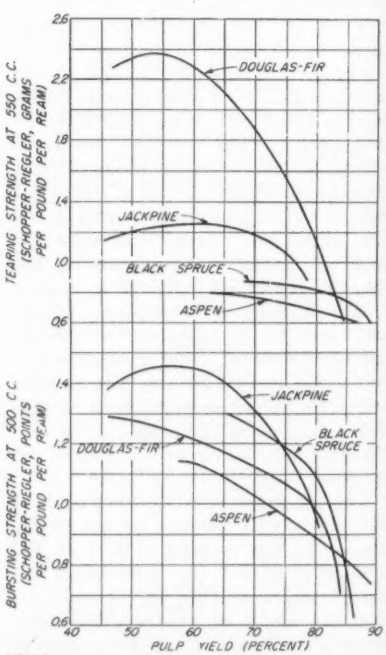
TEARING STRENGTH AT 550 C.C. (SCHOPPER-RIEGLER, GRAMS PER POUND PER REAM)
BURSTING STRENGTH AT 500 C.C. (SCHOPPER-RIEGLER, POINTS PER POUND PER REAM)
DOUGLAS-FIR
JACKPINE
BLACK SPRUCE
ASPEN
PULP YIELD (PERCENT)

Figure 4—Relation of bursting and tearing strength properties to yield of neutral sulfite semichemical pulp.

shown in *Figures 3 and 4*. Data are presented for a yield range of about 45 to 75 per cent of both neutral sulfite and sulfate processes. In general, strength decreased with increase in yield. After the maximum strength was reached, strength generally decreased with increase in yield more rapidly in the sulfate than in the neutral sulfite semichemical pulps, except for tearing strength, which did not show as much change as the other properties. The sulfate pulps were higher in tearing resistance than were the neutral sulfite semichemical pulps.

The general effect of pulping with different chemical reagents on the major chemical fractions of the wood is shown pictorially in *Figure 5*. The top bar represents the major components of a hardwood. Lignin amounts to about 22 per cent of the total. The hemicelluloses are represented by a length on the bar corresponding to the material extracted by a 17.5 per cent solution of sodium hydroxide. The cross-hatched portions of the bars, representing the different semichemical processes, are measures of the wood fractions that were removed in pulping to a yield of 75 per cent. The neutral sulfite process removed about 40 per cent of the lignin. In the acid sulfite process, about 50 per cent of the lignin was removed. The alkaline reagents attack the wood fraction that is soluble in caustic soda before they attack the lignin and thus take out less lignin than the others. In sulfate semichemical pulping, the lignin removed is 30 per cent and, for soda semichemical pulping, it is only 20 per cent.

The considerations for hemicelluloses and alpha-cellulose are not so simple as for lignin. First, the analytical methods available make it difficult to distinguish between the various carbohydrates lost in pulping. Secondly, there is a transition during a pulping process from resistant cellulose to hemicelluloses. In the alkaline processes, as shown in *Figure 5*, somewhat more of the hemicelluloses are removed than in the other processes because of the solubility of the components of this fraction of wood in alkali. The greatest removal of pentosans, which are a very important component of the hemicelluloses in hardwoods, is by acid reagents, the next weakest by the neutral sulfite process, and the least by the alkaline processes. The chemical composition of pulps made by the different pulping liquors can be directly related to the nature of the chemical reactions between the liquors and the wood.

Bleaching of Semichemical Pulps

Bleaching of semichemical pulp is possible and results in a remarkable occurrence, namely, an appreciable increase in strength of the pulp. The pulp, of course, also attains a high brightness so that its utility is greatly increased. Instead of just being suitable for boards, the pulp gains properties that permit its use for fine papers. Several mills now make this type of pulp and several others are under construction.

Semichemical pulp can be bleached by two general methods. One is a single-stage process and the other is a multistage process. In the single-stage process, the action is essentially a pulp brightening, similar to the brightening of groundwood pulp. The bleaching can be done with calcium or sodium hypochlorite or peroxides. In this latter process, the lignin content of the pulp is not reduced and its properties are much the same as those of the unbleached pulp, but the brightness is increased by an increment of up to 20 per cent.

In multistage bleaching, most of the lignin is removed and the bleaching can be controlled to remove as much of the hemicelluloses as desirable. Multistage bleaching usually includes chlorination, extraction, and oxidation, similar to the bleaching of full chemical pulps. The brightness may be as high as 90 per cent. The bleach requirement is relatively high, because of the removal of lignin amounting to 10 per cent or more of the pulp and the total shrinkage is 20 per cent, so that the final yield of bleached pulp ranges from 55 to 60 per cent. The strength of the bleached pulp is, in many ways, comparable to the strength of bleached softwood sulfite pulp. Many of the uses for which softwood sulfite pulp finds outlets can also be outlets for bleached semichemical pulps.

General Properties and Uses of Semichemical Pulps

Hardwood semichemical pulps are characterized by relatively high strength, rapid development of strength, short fibers, tendency toward slowness, high hemicellulose content, and relatively high shive content. The unbleached pulps from woods like aspen, birch, and gum show 80 to 90 per cent of the developed strength of softwood sulfite pulp but do not possess the high tearing resistance of lightly processed sulfite pulp and are appreciably lower in folding endurance. Semichemical pulps from some woods, like oaks, may be weaker than those from aspen, birch, and gum. The strength of semichemical pulps from these woods, however, is superior to that of hardwood sulfite and soda pulps and approaches that of sulfate pulps from the same woods. The bleached pulps from aspen, birch, and other hardwoods are appreciably stronger than the unbleached pulps from these woods and as strong as, or stronger than, bleached softwood sulfite pulps, except for lower folding endurance in some, but not all, cases. The bleached pulps are equal or superior in strength to pulps by other processes from the same woods, but are lower than bleached northern softwood sulfate pulps. The bleached pulps are softer, more absorbent, and have more flexible fibers than the unbleached pulps.

Papers and boards from the semichemical pulps are hard, stiff, and low

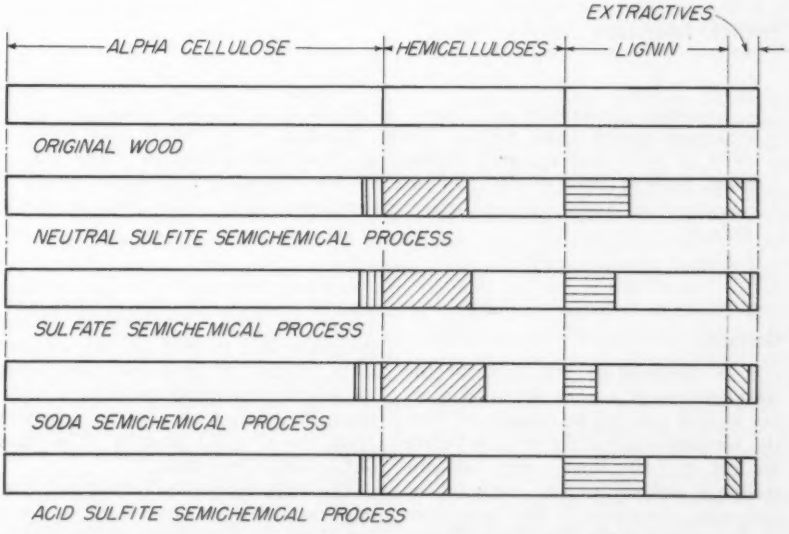

Figure 5—Removal of the major chemical fractions of the wood in semichemical pulping of a hardwood to 75 percent yield by several processes.

in opacity but these properties can often be offset effectively by blending with softer, more opaque pulps. Unbleached semichemical pulps are used mainly in corrugating board to take advantage of the stiffness of the semichemical fibers and in specialty boards such as book, match, and bottle cap, and certain grades of wrapping paper. These pulps have also been used in insulating board, hardboard, and roofing felt. Trial runs have indicated promise for use in liner boards, and experimental runs have indicated the possibility for use of light-colored semichemical pulps in newsprint. The pulps should find wide use in groundwood products containing unbleached softwood sulfiite pulps.

The bleached pulps are now used mainly in coated book and magazine cover papers. Experimental and mill trials have indicated strong possibilities for use of the bleached hardwood semichemical pulps in grease-proof, glassine, book, bond, waxing, carbonizing, and other bleached specialty papers and in towel papers. The pulps could be adapted to bleached food carton and waxed liners, specialty boards, and ledger and envelope paper. The bleached pulp should also find use in many products containing bleached softwood sulfite pulps.

Recovery of Semichemical Spent Liquor

When semichemical pulping is conducted with sulfate liquor in conjunction with a kraft mill, as is usually the case, the spent liquor can be processed in the kraft-mill recovery system. The sulfate semichemical cooking liquor can also be made by diluting the kraft white liquor.

In the starting days of semichemical pulping with sodium sulfite, the economy of the process did not demand that the cooking chemicals be recovered. The pulp yield was high and the chemical cost per ton of pulp was low enough so that a mill could afford to throw away the spent liquor. This was done then and is still done today in many mills. Increasing demands for reduction of stream pollution, however, are forcing semichemical mills to find ways of recovering the values in the spent liquor and thus eliminate stream pollution. There is considerable activity in this field, as well as in recovery of sulfite waste liquor, which presents similar problems.

There are several methods that seem to be technically feasible, and one method, at least, that is in practice. This method involves evaporation and burning of the neutral sulfite spent liquor along with the black liquor in a kraft-mill recovery system. It furnishes sulfur and sodium as make-up chemicals for the kraft mill and the semichemical mill starts with fresh chemicals for each digestion. Several mills are operating successfully in this way, and it is a good solution to the problem of semichemical recovery. It has the disadvantages, however, of being dependent on association with a kraft mill and of having its production limited because the capacity of the kraft mill to absorb recovered chemicals is limited to a fraction of its own production; roughly one-third, depending on the make-up chemical requirements.

The other alternatives, which are under examination and show promise, involve evaporation of the neutral sulfite spent liquor and (a) burning under controlled oxidation conditions to solium sulfite or (b) burning to sodium sulfide and sodium carbonate and conversion of the sulfide to the sulfite. The conversion of sodium sulfide to sodium sulfite can be effected by a wet, low-temperature oxidation or by carbonation with carbon dioxide to form sodium bicarbonate followed by sulfiting of the carbonate.

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Soda Pulping

Franck Morrison

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General

It is proposed to first describe the soda process in a very informal manner so that you will be acquainted with the fundamentals of the process before we get into the finer points and the technical end of it. The basis of the following discussion is the experience of the author at the Penobscot Chemical Fibre Co., particularly with the flow of materials and processes used.

The soda process, so called, was invented by Watt and Burgess during the years 1853 to 1854; so you see that it is nearly 100 years old and must have been a good process to have withstood the years with very few changes from the original process as worked out by these two men.

The soda process will cook any kind of wood that you may want to cook, but there are limitations to the resultant pulps. If you want an easy bleaching pulp you must use one of the broadleaf woods. These commonly are poplar, birch, maple, balm of gilead, willow, etc. If you do not desire to bleach the resultant pulp you may use the coniferous woods. The latter was the kind of pulp produced at the Penobscot Chemical Fibre Company when it was first started in 1882.

The wood or trees are cut down, peeled, and sawed into four foot lengths in the spring while the sap is in the tree. These bolts are then piled awaiting transportation to the mill. Transportation may be by truck or rail directly to the mill, or by driving in the streams and rivers. The hardwoods,

of course, such as maple, birch, and beech cannot be driven since they will float for only a short period of time. Poplar can be, and is, put into the water and is driven long distances. It will keep its ability to float for about four to five months after which it becomes waterlogged and will sink. Upon arrival at the mill, the wood not being used immediately is piled in large piles which may hold as much as 16,000 cords and is held there until called for by the mill.

The wood is hauled from piles, or directly from unloading, to the mill where it is conveyed to a chipper which cuts the sticks of wood into chips of a size suitable for cooking in the digesters. Poplar is not mixed with maple and birch since these different density woods require different cooking methods. The chips are conveyed to a chip storage from which they are fed to the digesters as needed.

The chips are fed into the digesters, which are large cylindrical steel vessels holding about 11 cords of wood in the form of chips. The cooking liquor is then added and steam is admitted until the digesters have reached a predetermined pressure and temperature. They are then held at that temperature and pressure for the required length of time. At the end of the cooking period, if the pressure is gradually reduced, when the cover is taken off the digester there will be apparently no change in the form of the chips. They will be brown in color but otherwise look just the same as when they were introduced into the digester. They will, however, be very soft and easily broken or rubbed into fibers. The lignin which held the cellulosic fibers together has been more or less removed by the cooking liquor. Therefore, at the end of the cooking time, the chips are blown out of the digester, from a high pressure, into a blow tank at atmospheric pressure. The sudden release of pressure simply blows the chip apart and separates the individual fibers.

This mass of pulp fibers and the spent cooking liquor are then put into tanks where the liquor is drained away and the fibers are washed with water until all of the spent cooking liquor has been removed. This liquor must be removed not only from the surface of the fiber but also from the interior of the fiber. The washed fibers are then conveyed to the screening and bleaching room. The spent cooking liquor which was drained and washed from the pulp goes to the evaporator room. In the screen and bleach room the pulp is screened first to remove the large knots and uncooked chips and is then screened again through fine screens to remove the very fine slivers or shives of uncooked wood. The pulp is washed again and after screening is subjected to the action of a bleaching agent, usually calcium hypochlorite.

The bleached fibers are white and ready to be used in the manufacture of paper. The fibers are washed free of any remaining bleach and then screened again to remove any dirt they may have picked up. Since the Penobscot Chemical Fibre Co. makes pulp only, they are then pumped to the pulp drying machines where they are formed into a thick sheet. This sheet is passed over a series of heated rolls until the moisture content is reduced to about 18 or 20 percent. The rolls of pulp thus formed are shipped to the customer who uses the pulp in his manufacture of paper.

The black liquor which we left at the wash tanks is pumped to the evaporators where water is evaporated until a specific gravity of about 1.33 is obtained. At this point it has a solids content of about 65 percent. These solids consist of dissolved lignin and the sodium organic compounds formed during the cooking of the wood. At this high concentration it looks like very thick molasses except that it is black in color. The black liquor is burned in a furnace of which there are several types, to recover the soda for eventual reuse after proper processing and also to produce steam generated by the heat of combustion. The burning of the organic substances converts the sodium compounds to sodium carbonate. This sodium carbonate is then dissolved in water and by treatment with milk of lime is converted back to sodium hydroxide, for reuse as a cooking liquor.

Wood Preparation

We will now start at the beginning again with the wood as cut in the woods and go through the entire process and try to present the old and the modern methods, the whys and the wherefors of each, and the advantages and disadvantages of each.

In the woods it has been found that peeling the wood as it is cut has several advantages. Among them are the following: (1) The wood has less calcium carbonate content when peeled as cut; (2) the wood is cleaner; and (3) it is an advantage to the mill to have wood scaled after peeling since the loss due to barking at the mill is an undetermined amount and may vary considerably. However, a manpower shortage, such as occurred during the last war, may require that the mill take rough wood and bark it at the plant.

There are at least three different methods of barking a pulpwood stick. In drum barking, the wood enters at one end of a large, cylindrical steel drum which is rotating on its long axis. The wood is tumbled over and over while being wet with a stream of water and finally emerges from the other end of the drum. The tumbling and rubbing results in the bark being rubbed or bruised away from the log. The water washes the bark out through slots or perforations in the drum. It is a very slow process and if the wood has been cut for some time the removal of the bark is, to say the least, only fair. In addition, the tumbling of the wood brooms the ends of the sticks which causes considerable loss, because these broomed pieces are broken off and washed away.

A second method of barking is the knife barker. In this operation the sticks of wood are held against a disc carrying several knives on its face which literally shave the bark off the wood as it is rotated against the disc. This, as you can imagine, is very wasteful and is seldom used.

One of the newest methods of barking rough wood is with the hydraulic barker in which the wood enters the end of a chamber on a conveyor which rotates the wood as it passes through the chamber. On its way, it is hit by sprays of water which are at very high pressure, usually at least 800 pounds per square inch or more. The extremely high pressure of the stream of water literally cuts the bark from the wood. It is reasonably efficient and rapid, being able to handle from six to eight cords per hour. It also has several drawbacks. The power consumption is very high. If a stick gets stuck in the chamber, or if it is unevenly round and requires considerable time to go through the chamber, then the streams of water may cut deeply into the stick and there is considerable waste of wood.

In all of these methods of barking the problem of the disposal of the bark is a factor. It may be used as fill in low land or it may be burned. The probable value as fuel is doubtful since the water has to be pressed out of the bark, or it must be dried by some other means until the moisture content is low enough so that it will burn.

After the wood is received at the mill it is usually stored in piles which may contain as much as 16,000 cords of wood per pile. However, it is not good practice to hold more than a year's supply of wood at a time as the wood becomes "dozy" and "punky." The action of fungus destroys some of the cellulose so that the yield of pulp from such wood is not as good as with clean, fresh wood. Not only is the yield poor, but also the pulp produced from this dozy wood is much harder

to bleach and wash. Prolonged storage also means a greater accumulation of dirt in the cracks and this is harder to remove before chipping.

Wood that has been driven down the rivers is usually not piled but is taken directly from the river to the chipper. This wood, for some reason, seems to cook much more easily and the resultant pulp washes and bleaches easier than pulp made from the best of wood in a pile.

Wood is conveyed from the piles, the river, trucks or rail cars to the chipper room where it is first washed thoroughly to remove all loose dirt. It is also inspected and any sticks having bark remaining on them are put to one side for cleaning. Large sticks which will not go in the chipper are split so that they may be accommodated.

The old style chipper was usually a four knife affair. The disc was about eight feet in diameter. Set into the face of the disc were four knives about 20 inches long. The wood came down a chute at an angle of about 60 degrees with the face. As the disc rotated each knife cut off a slice the full area of the stick and about five-eights inch thick. Modern practice is to make the disc considerably larger and to have 8, 10, or 12 knives on the face of it. This means much greater capacity and also more uniform chips, as the sticks do not have a chance to bounce back away from the disc after one knife cuts it and before the next one cuts it.

The slices of wood are broken up as they pass through the knife slots. The chips fall onto a belt where they are conveyed to a screen where the acceptable chips are removed from the sawdust and the large chips. These screens are of several types, among them being the rotary, flat-shaker, or vibrating screens. The older rotary screen was slow, of small capacity, and power consumption was high. It was a rotating cylinder similar to a gravel screen with small holes at one end to remove sawdust, followed by holes of the right size to pass acceptable chips. Large chips and sticks were discharged at the lower end.

Next came the flat-shaker screen which consisted of two flat inclined screens one above the other which were given a violent shaking motion by means of eccentric and push rods. The top screen had holes about seven-eights inch by two inches and the sawdust and acceptable chips fell through onto the second of the screens. The large chips continued to the end of the screen where they were discharged to a crusher. The chips fell through the top screen to a second screen which was a wire mesh about one-fourth inch in size. The sawdust passed through the mesh to a scraper which carried it to a blower and from there to the boiler room. The good chips came off the end of the second screen and was carried by conveyors to chip storage or directly to the digesters. The large chips which went to the crusher were broken up by a hammer, or finger type, crusher and were returned to the screens again.

This screen did a good job but the space required was large and, although the power consumption was not very high, the maintenance cost was large.

The newer types of screens are the vibrating type, in most cases similar in construction to the flat-shaker screen, but instead of being shaken back and forth the chips vibrate and as they fall down the inclined screens, sawdust goes all the way through and the large chips are retained on the top one. These screens require less space and have a larger capacity and require about the same power to operate as the flat-screens. The maintenance seems to be much less, also.

The older method was to convey the chips to a chip bin above each digester, holding about enough to fill the digester. Modern practice is to have a storage for chips in a separate building, holding enough for several digesters and to convey the chips to the digesters as needed. This is much more satisfactory as it lessens the height of the digester building and the consequent expense of a heavy, strong building construction to carry the weight of the chips. Also, the ground level storage permits the storage of a considerably larger amount of chips so that sufficient chips may be made and stored in as little as one half of the working day, thus saving labor.

Digester

After the digesters are emptied, chips are conveyed from the bins into the digesters. They are filled by packing with mechanical packers, steam distributors, or other means to get as many chips into the digester as possible. At the same time as the chips are put into the digester the cooking liquor is also run in and the circulation started. A small amount of steam is also turned on. The purpose of adding the liquor and steam at this point is to soak the chips and make them pack better.

Perhaps a few remarks as to the types of digesters used is in order. For soda pulping some mills use horizontal digesters which rotate on their long axis. These have an advantage in that circulation is not a problem but have the disadvantages that maintenance is rather high due to leaks and heat loss is high. Most mills use the stationary, vertical digesters and it is to this type that I will confine myself. These are large cylindrical steel cylinders, with convex ends, set upright. The bottom of the digesters has a false bottom made of perforated steel plate in the form of a cone tapering from the sides to the opening for the blow line. The purpose of this false bottom is to allow the liquor to drain through the chips and then out to a circulating medium, usually a pump, which continually transfers the liquor from the bottom of the digester to the top, thus uniformly wetting and cooking the chips. Steam is usually introduced under this false bottom if the digester is heated by direct heating. If the digester is heated by indirect heating then the liquor is pumped out from under the false bottom into a heat exchanger and then back into the digester. The advantages of each method are evident. In direct heating, economy in steam and upkeep are the advantages. In indirect heating, the big advantage is in non dilution of the cooking liquor so that a more uniform cook results.

Digesters are made up of plates with riveted seams or welded seams or a combination of both. We, at the Penobscot Chemical Fibre Co., due to a lack of room, have to construct the digesters in place and so we have used the riveted seam digester followed by welding.

There is considerable wear of the inside of the digester due to the mechanical action of the liquor and chips. There is also apparently, according to the latest discoveries, some galvanic or electrical action so that it is deemed advisable to ground the digesters. However, careful inspection and maintenance will allow a steel digester to be used for about 15 or 20 years before a dangerous condition exists. Some of the mills are trying stainless steel digesters, either clad or solid, but results are inconclusive to date and the expense is quite high. We have tried lining the top one-third of the digester with Inconel plates welded to the steel shell and apparently it has some merits. Most, if not all, of the wear in a digester seems to occur at the top point where the chips settle during cooking.

Cooking

After the digester is filled, the cover is put on and the steam turned on full to bring the digester up to pressure as quickly as is feasible. The circulation pump is started to keep the liquor moving and then the relief valve is opened. The relieving of a digester is a very important part of the cook. It serves two purposes. First, it removes all of the air trapped in the chips and digester and all of the gases formed from the action of the caustic on the chips so that the temperature of the digester will follow a true steam temperature-

pressure relationship. If the gases are not relieved the pressure will increase but the temperature will not. This is definitely undesirable because it is elevated temperature that cooks the chips. It is therefore important that all of the air and gases are removed and yet if the relieving is overdone, steam and heat are lost and expenses mount. Secondly, the relieving stimulates circulation inside the digester. You can thus see what an important part this plays in the proper cooking of wood. Relief is continued at a very reduced rate during the entire cooking period after the digester has been brought up to the required cooking temperature. After cooking for the required time, the steam is shut off to allow the introduction of spent cooking liquor for blowing.

Let us leave the digester at this point and go back to the cooking liquor. The cooking liquor is a solution of sodium hydroxide, caustic, in water, As the caustic is necessarily a reclaimed chemical, it is contaminated with sodium carbonate to the extent of about ten percent. This sodium carbonate has no effect on the cooking of the wood. The amount of caustic added to cook the digester varies with the kind of wood being cooked and the resultant type of pulp that is desired. For a medium-well cooked pulp made from poplar wood, the weight of caustic will be about 23 percent of the weight of the wood. For the same kind of pulp made from maple the amount of caustic required will be around 31 percent. The digesters used at the Penobscot Chemical Fibre Company each hold about 11 cords of wood or 28,000 pounds of bone dry wood. Therefore, we add about 9,100 pounds of caustic to a digester of poplar wood and about 11,500 pounds for a digester of hardwood.

The weight of caustic is important but so is the concentration of caustic. The concentration must be such that the cooking liquor volume will be sufficient to cover the chips at all times or the chips may burn and not cook evenly. The moisture in the wood must be measured at frequent intervals so that the volume of cooking liquor may be regulated. With a moisture content of about 25 per cent we use a volume of 10,500 gallons of liquor and vary this amount as the wood varies in moisture content. The concentration of liquor is also important because the smaller the amount of liquor the less steam will be required to heat it.

The normal cooking schedule for a digester is as follows: About two hours are required to bring the digester up to a temperature of 340 degrees Fahrenheit and a pressure of 105 pounds per square inch gauge. The digester then is held under these conditions four hours after which time the contents are blown to the blowpit.

Modern cooking practice is to use an automatic cooking control. It consists of a temperature and pressure element combined with a time cam. As the time cam turns, it follows a pre-determined curve and the instrument introduces steam to keep the temperature at the same point as the follower on the cam. If the pressure inside the digester rises faster than the pressure-temperature relationship calls for, the relief valve is opened to allow air and gas to escape. As soon as the temperature and pressure correspond, the relief valve is shut, thus economizing on steam. After the digester reaches the high point of the curve on the cam, steam is introduced only in sufficient amounts to keep the digester temperature at that point. Relieving also is controlled then so that there is only a small amount carried on for the remainder of the cook.

At the end of the turn of the cam the steam is shut off, the relief is opened, and a signal sounded so that the cook will be able to know it is ready to blow.

In cooking with caustic soda, it is quite important that a digester be blown promptly at the end of the cooking period, because if not blown the caustic will continue to act on the wood and will yield an overcooked pulp which, while easier bleaching, will be much harder to wash in the next step. Also, the continued action of the caustic will result in lower yields of pulp.

After the digester is relieved to about 90 pounds pressure preparatory to blowing, spent liquor from the washing system is pumped into the digester to dilute the chips and the blow valve is opened as quickly as possible.

When the blow valve on the bottom of the digester is opened suddenly, the mixture of chips and liquors are blown into the blow pit. The sudden release of the pressure of 90 pounds down to atmospheric pressure simply explodes the chip into individual fibers.

The blow pit is a large, cylindrical steel vessel with a cone shaped bottom holding about two times the capacity of a single digester. The chips are blown into it tangentially near the top and the stock or pulp falls to the bottom. The steam released from the pulp rises to the top and is led to a heat exchanger to heat water used throughout the mill. The amount of heat liberated in the steam from a digester holding 26,000 pounds of wood is in the neighborhood of 13 million or 14 million B.T.U. It is released over a comparatively short period of time, about 20 minutes, so that the heat exchanger has to have a very large capacity to handle all of the steam. As a matter of fact, there is an economical limit to the size so that actually some of the blow steam is lost to the atmosphere.

Washing

The mixture of stock and cooking liquor in the blow pit is a dense, black color. The liquor must be washed out and saved since it contains the sodium compounds that are reprocessed into new cooking chemical. This is done either on vacuum washers or in wash pans. The vacuum washers are the newer of the two processes and, briefly, consist of a wire covered cylinder rotating in a tube of the dilute stock. A vacuum applied to the interior of the cylinder draws the liquor out of the stock and leaves the stock in a mat on the surface of the cylinder. It is washed under that same vacuum by sprays of water until it is clean.

The old fashioned wash pans or tanks are the means by which we wash stock at the Penobscot Chemical Fibre Co. They require a great deal less power and maintenance than the vacuum washers and the recovery of cooking liquor is usually greater. However, they require much more space. In the wash tanks, the stock is piped from the blow pit into a series of steel tanks, each holding about 6,000 pounds of dry stock. The tanks are arranged in a rough circle, so that a swinging pipe from the blow pit will fill any desired tank. As soon as a tank is filled from the blow pit, weak liquor from a half washed tank, previously filled, is pumped onto the top of the stock. The strong liquor drains out through a false bottom in the tank and is piped to the evaporator at the start of the recovery cycle. Some of this liquor is the liquor used to dilute the digesters before blowing. As soon as the strength of this draining liquor has begun to decrease, it is taken from the pump to the evaporators and is then used to wash the tanks last filled from the blow pit. After a period of washing with weak liquor, the stock is drained of the liquor and water is put on. This water is kept on the stock until the liquor draining through the false bottom has reached such a low concentration of chemicals that it is no longer economical to recover it and then the stock is ready for bleaching.

The big advantage of the wash tanks is that the soaking action of the weak liquor and the water will entirely remove the chemicals and black liquor from the interior of the fibers which the vacuum washer will not do as well. It takes about six hours to wash 6,000 pounds of stock in comparison to the vacuum washers which take from two to four minutes. The more complete removal of spent liquor, the easier the

stock is to bleach and handle. Also, the percentage recovery of chemical is that much higher.

Screening

Upon leaving the wash room, whether it be wash tanks or vacuum washers, the stock goes over a coarse screen of about one-fourth inch mesh and then goes over a screen of about 0.060 inch mesh. These screens are of several types, flat vibrating, inclined, or rotary. They all produce the same results, namely, the removal of the big knots and pieces of uncooked wood by the coarse screen and the removal of fine shives and dirt by the fine screens. The consistency of the stock while in contact with these screens is in the neighborhood of 0.5 per cent. After screening, the stock goes to a washer which removes any remaining traces of liquor. This is usually a cylinder washer, operating either under vacuum or under a couch roll which presses out the wash water in about the same manner that the wringer on a washing machine does. The consistency of the stock leaving the washer will vary from 15 per cent with the vacuum washer to about 7 per cent with the couch roll.

Bleaching

The stock from the washers then goes to the bleachers. The old method of bleaching was to put the stock at about 4 per cent consistency into large wooden chests, heat it up to about 120 degrees Fahrenheit, add a strong solution of calcium hypochlorite as bleach and allow the mixture to stand under agitation for about four hours, or until the stock had reached the required color or the bleach was exhausted. This system gave very good results as far as color was concerned, but it was expensive. A large quantity of bleach had to be used and the high temperature, in conjunction with the strongly oxidizing bleach, attacked the cellulose fiber and caused considerable weakening of the fiber as well as loss in weight.

Most mills today use a two or three stage bleach. The stock at three or four per cent consistency is first subjected to the action of chlorine gas, admitted as a gas or as a solution of the gas in water. The chlorine partially bleaches the stock and has a strong action particularly on uncooked shives. The stock leaving the chlorination process is washed again on a vacuum washer. This removes the materials that have been made water soluble by the chlorine. It is then made slightly alkaline with sodium hydroxide. This treatment makes another quantity of chlorinated materials soluble and these are washed out on another washer. The stock is washed here until the stock is nearly neutral, a pH of about eight, and is then conveyed to high density bleachers at a consistency of about 16 per cent where it is heated to about 90 degrees Fahrenheit and calcium hypochlorite bleach is added.

The total chlorine demand of this process is about 25 per cent less than the older method and produces a stronger pulp with less loss in weight, although the resultant color is perhaps not quite as good. After holding in the bleachers until it has reached the required color, the stock is diluted to about one per cent consistency and pumped to another washer where the residues of the bleaching process are removed. The stock is then ready for the paper machine or, as in our case, the pump drying machine. Here it is formed into a thick sheet on a cylinder machine and dried to about 80 per cent air dry and is then baled or made up into rolls which are shipped to various paper mills.

Soda Recovery

Now let us return to the wash tank room where we left the black, or spent, liquor being pumped to the evaporator room. The whole economics of the soda process depend upon the recovery of the caustic soda used in the cooking because of the large quantities and expense of the sodium hydroxide used.

The black liquor as it leaves the wash tank room is about 13 degrees Twadell or 1.065 specific gravity and at a temperature of about 180 degrees Fahrenheit. This liquor is stored in a large tank as a supply for the evaporators. The analysis of this liquor shows it to have a solids content of about 187 grams per liter, the balance being water. The solids at this point consist of about 20 per cent free sodium carbonate, 3.3 per cent free sodium hydroxide, 16.8 per cent combined sodium hydroxide, 5 per cent sodium chloride, and 54.9 per cent organic matter. In order to convert all of the sodium compounds to sodium carbonate, so that it may be later converted to hydroxide, and so that the heat value of the organic matter can be utilized, it is necessary to evaporate the water to a point where the organic matter will burn and at least support its own combustion.

This evaporation is done in any one of a number of different kinds of evaporators, all of which produce the same end result. All evaporators in use today are of the continuous type and are of three or more effects. Some admit the weak liquor and the steam at the same effect and some, the more modern, admit the steam at the last effect where the liquor is the most concentrated. In either case, the liquor travels from one effect to the next where it is exposed to higher and higher vacuum so that in the last effect the vacuum may be as high as 28 or 29 inches of mercury. This high vacuum causes the liquor to boil at greatly reduced temperatures and therefore leads to very economical steam consumption. In fact, the most modern of five or six effect evaporators will have a steam economy of evaporating about five pounds of water for every pound of primary steam used. Typical evaporation as obtained in some very old fashioned evaporators which we now have, and soon hope to replace, are as follows:

Liquor enters the first effect at 160 degrees Fahrenheit and a density of 15 degrees Twadell and a solid content of 18 per cent.

Liquor leaves the first effect at 141 degrees Fahrenheit and a density of 21 degrees Twadell and a solid content of 24 per cent.

Liquor leaves the second effect at 166 degrees Fahrenheit and a density of 29 degrees Twadell and a solid content of 34 per cent.

Liquor leaves the third effect at 142 degrees Fahrenheit and a density of 63 degrees Twadell and a solid content of 57 per cent.

At the Penobscot Chemical Fibre Company we then pass this liquor through a single effect, calandria type of evaporator, to further evaporate it to 228 degrees Fahrenheit, a density of 65 degrees Twadell and a solids content of 64 per cent.

This liquor is then stored at the burner in a large storage tank where it is kept hot. If not kept hot, it is so viscous that it will harden at room temperatures.

The concentrated liquor is then burned. The old method was to burn it in a rotary furnace. Liquor was introduced at one end of a firebrick lined steel drum rotating slowly on its longitudinal axis. A fire box at the other end which was fired with coal kept the liquor hot and burning. As the liquor progressed along the drum it soon dried out and the organic matter started to burn. The heat produced by this organic matter burning plus the heat introduced by the coal converted all of the sodium compounds, in the presence of carbon, to sodium carbonate. The red hot ash, which was a mixture of almost pure carbon and sodium carbonate, tumbled out of the end of the drum into water-filled tanks where the sodium carbonate was leached out of the carbon. The excess heat created by the burning was utilized in a fire-tube boiler where steam was generated for use in the mill. This was a very inefficient method of heat recovery be-

cause considerable carbon was not burned but simply wasted.

The newer methods of chemical recovery consist of a large furnace into which the black liquor is sprayed as a fine mist. The remaining water in the black liquor is almost instantaneously evaporated and the organic matter starts to burn. Air is admitted under controlled conditions so that all of the carbon is burned to carbon dioxide. Part of this carbon dioxide, in turn, reacts with the sodium present to form sodium carbonate. The heat produced is so intense that the sodium carbonate is melted and runs out of the furnace in a continuous stream at about 1650 degrees Fahrenheit.

The hot gases pass through a modern boiler where the steam for the mill is generated. At our plant about 40 per cent of the steam requirements of the mill are produced in the recovery boiler in contrast to 10 per cent produced in the old rotary furnaces.

A molten sodium carbonate drops out of the furnace into a dissolving tank where it is dissolved in water. It is then filtered to remove any unburned carbon and pumped to the causticizing department.

In the causticizing department, the solution of sodium carbonate is mixed with a solution of hydrated lime in a tower where it is heated to the boiling point and agitated with a small amount of air. The chemical action here converts the carbonate to hydroxide and forms calcium carbonate as the by-product. The mixture of these two, sodium hydroxide and calcium carbonate, is then pumped to a decanter where the calcium carbonate settles to the bottom and the clear solution of sodium hydroxide over-flows the top.

Conditions of causticizing have to be very carefully controlled. In order to maintain the strength of the resultant sodium hydroxide, the concentrations of the lime and the carbonate have to be maintained at a certain point. At this point only about 90 per cent of the carbonate can be converted to hydroxide. The addition of more lime will raise this percentage but in so doing, an excess of calcium hydroxide is present and this will not settle in the decanter which follows. Also, the lime must have a very low percentage of magnesium since the magnesium carbonate formed will not settle either. The calcium carbonate slurry at the bottom of the decanter is pumped off to a set of filters where the cake is washed to remove all of the sodium hydroxide possible. In many mills, the remaining calcium carbonate is reburned to form fresh calcium oxide. At the Penobscot Chemical Fibre Co. it is diluted with water and pumped to the sulfite mill and is used to make sulfite cooking acid.

The clear solution of sodium hydroxide which over-flows the top of the decanter is conveyed to the liquor room where it is diluted or strengthened, as conditions dictate, to make a cooking liquor of the proper concentrations.

In most mills the addition of chemicals to the process to make up for losses is in the form of sodium carbonate before causticizing. At the Penobscot Chemical Fibre Co., however, where we have our own electrolytic cells for the manufacture of chlorine, we make sodium hydroxide as a by-product and this is used as the make-up chemical. It is generally conceded that to be an economical mill the mill must recover at least 85 per cent of the cooking caustic to be reused.

We have thus completed the cycle and returned to the starting point of our cooking.

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Soda Pulping

Harold L. Field[1]

Born in Lowell, Mass., April 17, 1919. Raised and educated in Syracuse, N. Y. Was graduated from the Pulp and Paper Course of the New York State College of Forestry in 1942. Attained rank of Captain in U.S. Army during 3½ years of service. Joined Mechanicville Mill of West Virginia Pulp and Paper Co. in April, 1946 as Supervisor of Pulp Mill Research and Development. Operated and supervised operation of three different commercial-sized pilot wood pulping systems using the Kraft process. In 1949, promoted to Technical Supervisor of Mechanicville Mill as well as Coordinator of Technical Trainees. Acted as process designer for new commercial-sized N.S.S.C. pilot pulp mill completed in 1951 and its more recent expansion to a 100 ton per day process. Continuing to direct the development program in the N.S.S.C. mill and in the semi-chemical bleaching operations.

Introduction

An essential preliminary to a discussion of Soda Pulping or, for that matter, to a discussion of any other pulping process is that of deriving a practical definition. Originally, Soda Pulping might be defined as a steam heated digestion of wood chips under pressure in an aqueous solution of which caustic soda is the principal chemical pulping agent. However, since the advent of the kraft process and the realization by supervisors of soda pulp mills that advantages in pulp strengths and yield can be derived from the use of some sodium sulfide in the cooking liquor, the original definition is no longer completely valid, and there is considerable disagreement in the industry on a practical definition of "Soda Pulping." This is caused by the fact that sodium sulfide is now a component of the cooking liquor in almost all so-called soda mills as well as in all kraft mills.

Therefore, conflicting views have arisen concerning the point where the soda process ends and where the kraft process begins. Rather than arbitrarily decide where this point lies, I would rather mention where the conflicts are and leave it to you to decide what is actually the practical definition of the soda process.

Some authorities separate the kraft and soda processes on the basis of the percentage of sodium sulfide (sulfidity) in the cooking liquor. There are those who feel that anything over five percent is a kraft or semi-kraft cook. Others pick figures of eight percent; some as high as 12 percent. In most cases, mills whose liquors are as high in sulfidity as 12 percent are recognized as true kraft mills.

The chemical which is used to make-up for soda and sulfur losses is sometimes considered as a deciding factor in the conflict. Kraft mills normally use sodium sulfate for this purpose while the make-up chemicals in the soda process are normally sodium carbonate or electrolytic caustic, and possibly sulfur or by-product sodium sulfide from the petroleum industry.

The design of the recovery furnace is another way that some people distinguish between a kraft and a soda mill. The kraft process usually is equipped with a smelting type furnace for most efficient recovery of the sulfides. The soda process normally has a rotary type furnace where less efficient recovery of the sulfides is experienced.

Another feature which is sometimes used to distinguish between a kraft and a soda process is the type of wood used. That is not necessarily true because there are some hardwood kraft mills, but soda mills more often use the deciduous types of woods while the kraft mills, especially the Southern kraft mills, use mainly the coniferous woods. However, that is not a very good distinguishing characteristic because some new kraft mills and newly converted soda mills are now using hardwoods.

Economic considerations are sometimes used to distinguish between the soda and kraft processes. The soda pulping process is a full chemical alkaline pulping process in which the advantages of increased sulfidities in the cooking liquor are not justified in light of the added capital expenditures and/or the public nuisance involved. Pulp from the soda pulping process is generally used as a filler for paper and the mills involved do not consider it economic to operate at high sulfidities or to install a smelter type furnace to recover the sulfide content in the liquor. If they want some sulfide content in their cooking liquors they boil sulfur in caustic solution or use some other source of sodium sulfide. Although it is not economical to produce sufficient sulfidity in the cooking liquor to realize full advantage of a kraft cook by these means, small amounts of sulfide can be added to reduce the amount of screenings from those of a straight soda cook. This will result in a significant increase in screened yield. yield. Some increases in pulp strengths are also realized.

Another remark made in the foregoing discussion involved the public nuisance factor. Pulp mills that are close to large centers of population are sometimes limited by local ordinance in the amount of sulfidity they can use in their cooking liquor because of the pollution of the air which it causes. In a kraft mill, the air within several miles of the mill usually becomes potent with the odor of methyl mercaptans which are given off from the cook and from the recovery process. Even in the soda process where sulfide is used in the liquor, quite an odor is given off. As the sulfidity of the cooking liquor is increased, the odor becomes more potent. Some communities insist that only very little, if any, sulfidity be used in the liquor.

Development of the Soda Process

The soda process is recognized as the first successful chemical wood pulping process. It was pre-dated by several years by the groundwood process. Wood chips, like rags, were cooked in open vats with solutions of caustic soda and soda ash before the soda pulping process was developed. However, the pulps produced had very limited utility.

The principle of soda pulping was discovered in about 1851 by Burgess and Watt in England. In 1854, the first

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soda mill was built in America by Burgess, who had come from England the year before. His first digestions were made on poplar chips and a recovery system was connected with the process. The process as it exists today is basically similar to the process as it was discovered and developed by Mr. Burgess.

The soda pulping industry soon was thriving, and many mills were built in which both the coniferous and deciduous species of wood were used to make pulp. It was not until the late 1880's that this industry began to receive very stiff competition from the rising popularity of the newly developed sulfite process especially in the production of the long-fibered pulps. Unlike the coniferous sulfite pulps, the long-fibered soda pulps could not be bleached to high brightness in the single stage hypochlorite bleach, which was the only technique developed at that time. The soda process was then concentrated mainly on the production of deciduous pulps which could be bleached, while the sulfite process flourished on the coniferous pulps. In that way came a happy wedding between the soda process and the sulfite process in many mills that were making fine papers from wood pulps. The soda process made a bleached filler pulp which, although its use was limited by its low strength, gave many good characteristics to the paper such as a good felting quality, good formation, good printability, and so forth, while the sulfite process gave a pulp which gave very good strength to the paper. It was found that many mills could use these soda and sulfite pulps in various combinations to make a wide variety of papers. That, by the way, is the combination employed at the Mechanicville mill at the present time.

In contrast to this happy situation, the high cost of soda ash, which was the only commercial make-up chemical at that time, was destined to cause the downfall of the soda pulping industry.

The soda process was saved in many mills by the advent of the electrolytic process for making chlorine, the second product of which was soda ash and later caustic soda. This process reduced the cost of these chemicals so that the soda process was again able to compete with the sulfite process.

Since that crisis has passed the soda process has lost some ground as many soda mills are converted to the kraft process. In that soda pulp is of limited utility, there has been only very limited expansion of existing facilities in recent years, and virtually no new construction has been undertaken. However, many existing mills will continue to operate for an indefinite period.

The Wood and Its Preparation

Practically any wood can be used to make soda pulp especially if small amounts of sodium sulfide are introduced into the cooking liquor. Softwoods, such as pine, hemlock, fir, and spruce, produce an acceptable long-fibered, but hard bleaching, pulp. Poplar, (including aspen and cottonwood) which has probably been the most widely used, makes a very good filler pulp. More recently, the heavier hardwoods, such as beech, birch, oak, maple, and so forth, have been used separately and in mixtures in soda pulping to produce a filler pulp. The poplar gives a little cleaner and stronger filler pulp, but the hardwoods yield much more pulp per cord of wood. Softwoods average about 2100 pounds of solid, bone dry wood per standard peeled cord. The standard cord has 128 cubic feet in its outside measurements of which 90 cubic feet are solid wood. Poplar has about 2300 pounds per cord. Of course, the weights vary to some extent with the growing conditions, the specific species involved, and several other factors. The hardwoods run between 2700 and 3300 pounds per cord depending on species, etc., the oaks running as high as 3300, and the soft maples and other more common types running as low as 2700.

It is not absolutely necessary to supply peeled wood to the soda process. Before the recent war, this was considered quite essential, but during the war it was found that a fairly clean bleached pulp could be produced from rough deciduous species at some expense in quality, yield, and chemicals. Except for about a year, our Mechanicville Soda Mill has used rough wood since the beginning of the war. The use of peeled wood has advantages, but woods labor for peeling logs is now scarce and it is very difficult to bark hardwood in mechanical equipment that exists today. The inclusion of bark requires more severe cooking and bleaching treatments, consumes more chemicals, decreases the strength of the resulting pulp, reduces the pulp yield per cord, and adds some dirt to the paper, but where pulp strength is of secondary importance and sufficient peeled wood is unavailable, it is possible and very expedient to use the rough woods.

If sufficient peeled wood is available at the current price differentials between the peeled and rough, it is economical to buy the peeled wood in preference to the rough. Bark occupies an average of 12 to 14 percent of the wood volume. This loss is solid volume plus the increased processing costs are not compensated in the price differential.

The delivery of the wood to the mill is normally made by truck, rail, and sometimes water. Delivery by water includes driving the wood down a stream, rafting of wood for delivery across large bodies of water, and delivery by boat. It is usually supplied in short lengths of about four feet for easy manual handling. Companies sometimes use longer wood because they find it more convenient for their delivery, handling, and storage systems.

It has been found in the last few years by many mills which once drove wood down the river to the mill, that truck and rail deliveries, preferably truck delivery for short distances, have actually been cheaper than stream driving. Heavy hardwood logs usually cannot be driven or rafted unless they are first thoroughly seasoned in the woods because much of the green wood is dense enough to sink. Truck hauling is, of course, utilized for shorter distances, as is stream driving, while rail hauls are usually used for longer distances.

The wood coming to the mill by truck or rail is scaled to determine the amount delivered. This is often the basis for payment for the wood. It is important that the scaler look for rotten wood and for poor stacking in the ranks to be scaled. Rotten wood, or wood that has been deteriorated by standing a long time in the woods after it is cut, will still produce pulp in the soda pulping process but low quality of wood does decrease the yield and the quality of the pulp. Poor ranking reduces the solid wood delivered per cord.

The scaled wood is sent either directly to the chip house or to storage. In the yard storage, it can be put in ranked piles or in random (jackstraw) piles. River-driven wood can be stored in a pond or moved into yard storage.

Before the recent war, it was generally considered that long storage was necessary to condition the wood for the pulping process. Storage does help to even out the moisture content in different logs. It also sets, or oxidizes, the resins in the wood so that they do not appear in the pulp in a form of pitch which clogs and coats equipment. However, it has been proven in many instances that the value of this conditioning is not equal to the cost of the extra handling. It is better to maintain an inventory of wood only large enough to insure a continual supply to the mill. The bulk of the wood should be delivered directly to the chip house. In most mills in the North, where delivery schedules

are somewhat hard to meet at times, it is important to maintain a little higher inventory than in some of the Southern mills where deliveries can be scheduled almost to the day. Woods roads in the North are often in poor condition for several months of the year. In some localities where farmers deliver much of the wood, deliveries are sometimes erratic during their busy months. Most Northern mills, therefore, have to keep a minimum of two to three months inventory on hand.

Rotation of storage is very important. In other words, the first wood that comes into storage is the first that should go out. Where the wood is ranked, hooped, or jackstrawed (jackstraw piling seems to be the most popular way of handling wood in storage), there should be a way of rotating the storage so that no wood is there long enough to become severely decayed.

If a peeled wood is considered necessary to a mill's particular operations, and only rough wood is being delivered, the wood should enter the barking equipment either as it is delivered, or from storage. Several kinds of equipment are available. Both hydraulic barkers and barking drums will peel softwoods in a more or less satisfactory manner. Deciduous woods are much more difficult to peel, and those who have tried both types of equipment on them prefer the drum. Rossers can also be used for peeling relatively straight sticks of any type wood. There is a great promise held for the new chemical peeling techniques which are now under development.

The logs are chipped and the chips are then screened. The size and uniformity of the chips are not as critical as in the N.S.S.C. process and in the sulfite process where they are very important. A three-fourths inch chip along the grain of the wood is generally satisfactory. However, uniformity of chips is desirable and, therefore, the chips should be screened and the rejects should be crushed or rechipped. From the screens the chips are put in storage. Some storage is usually located above the digesters. This storage is desirable for uninterrupted operation of the pulp mill, but it must be quite small. It is also desirable to have a large storage of chips on ground level. This storage not only increases the assurance of uninterrupted production, but also blends the chips to supply chips of more average moisture content and blend of species.

Cooking Process

The cooking operation is the heart of the soda pulping as in any chemical pulping process. I have a definition for chemical pulping which covers equally well any such process and which, I feel, applies especially well to the soda process. A chemical pulping process is a process of selectively dissolving lignin and colored extractive materials from wood to leave a more purified cellulosic residue called pulp. This definition not only applies to the cooking process, but it also defines the further purification of the cellulose in most chemical pulp bleaching processes.

The lignin is the principal natural cementing material which holds the fibers together in the wood. Some or all of it is removed from the wood in pulping, first, to liberate the individual fibers to produce a pulp, and second, to purify the cellulose to the extent required to produce the specific quality of pulp needed for any particular purpose. Lignin is a substance which actually inhibits the attainment of high bonding strength in papers. However, its removal only improves the bonding strength to the extent that the chemical reaction required is selective on the lignin and only dissolves or degrades minor quantities of the bonding substances in the pulp. These bonding substances include hemicelluloses, pentosans and wood gums as well as the alpha cellulose.

I would like to give you a little more about the theory of cooking as it is applied specifically to the soda process. Caustic soda is the agent which does the cooking, as I mentioned before, and it reacts with the lignin to produce soluble sodium lignates (alkali lignins) and other reaction products. This is a simplified way of describing the cooking reaction. There is quite a field of chemistry in the actual reactions that take place. I am not going to attempt any discussion on this subject. Generally speaking, most of the lignin is dissolved, and is washed out of the chips and pulp.

During the process, however, there are certain parts of the desirable wood substances that are attacked, especially the more reactive hemicelluloses pentosans, and wood gums, so it is not a very selective condition. Some of these cellulosic materials are necessarily dissolved out when the reacted lignin is removed. The uninhibited caustic is not very selective on the lignin. In other words, the uninhibited caustic dissolves quite large amounts of cellulosic materials and extractives when it is attacking the lignin, even though it is much more selective on the lignin than it is on the cellulosic material.

The addition of sodium sulfide, even in minute quantities of two to five percent of the cooking liquor, inhibits the reaction between the sodium hydroxide and these cellulosic materials by holding this sodium hydrofide in reserve until it is ready to be used so that there is lower concentration of caustic available to react with the cellulose. This inhibiting action tends to reduce the reaction of caustic with the cellulose materials and in that way causes a much more selective reaction on lignin. It so happens that, at the beginning of the cook, the reaction between the caustic and lignin is very selective, but as more of the most active and available lignin is reacted easily, the remaining unreacted caustic tends to be more reactive on the cellulosic material. It is at this point that the sodium sulfide takes over to modify the reaction. Many of the weak links in the chain of the cellulose which are attacked in an uninhibited caustic reaction, are broken and the cellulosic material becomes broken down into smaller chains, and the fiber, therefore, becomes brittle and loses considerable strength. In the inhibited reaction with the sodium sulfide, these chains are kept in long lengths and are thus less brittle and weak.

The cooking process is carried out under a balance of cooking conditions which determine the qualities of the unbleached pulp from any given wood. There are five important variable cooking conditions as well as several other minor, valid or fancied, variables. Two of the important conditions have already been mentioned. One is the amount of active chemical (sodium hydroxide plus sodium sulfide) initially applied to the chips at the beginning of the cook. This amounts to between about 18 percent and 22 percent (as sodium oxide) of the weight of the oven-dry chip charge, when a bleachable pulp is desired. For pulps for papers and boards of lower brightnesses, somewhat lighter chemical charges are used. The other previously mentioned variable is the amount of sodium sulfide in the total active chemical which is charged. Many soda mills use no sodium sulfide while others use varying amounts depending on its economic value to their individual soda pulps. The third important variable is the initial chemical concentration. This is varied anywhere from about 55 to 70 grams per liter as sodium oxide.

Two other important variables are involved in the schedule of the cook while it is in progress. One of these is the total cooking time. This is the time from the moment the steam is first turned on to the time the blow valve is opened. This time varies between about three to about eight hours in different mills. The last important variable is the maximum cooking temperature. This varies between about 165 degrees and 180 degrees centigrade. Since penetration of the chips by the cooking liquor is very rapid in this process, most mills bring the temperature to a maximum in the shortest possible time, so that the schedule

of the temperature rise is of rather minor importance.

Although there are some other less important variables, any variations in qualities obtainable in a soda pulp from any wood can be effected by shifting the balance between these five important variable cooking conditions. For instance, a mill using no sulfidity would obtain some limited increase in pulp strength and yield by adding a limited amount of sodium sulfide to the cooking liquor. A slight decrease in the maximum cooking temperature might then cause some additional improvements in quality. However, such a move should be justified by an incentive which outweighs the increased chemicals costs, the increased public nuisance, and a somewhat decreased life of some pulping equipment.

Many shifts in variables to meet local mill conditions can also be made which will not materially change the qualities of the resulting pulp. For example, if more production is needed, some reduction in cooking time might be allowed if a slight increase is made in maximum cooking temperature and chemicals charged. With judicious adjustment of the balance in this way, no serious change in pulp quality should be expected. Other examples of changes could be cited which would either change, or leave unchanged, the qualities of the pulp.

There has been a growing realization that the physical strength of a deciduous soda pulp can be improved to the extent that greater percentages of this filler pulp can be used with sulfite or kraft in any given paper furnish. This is accomplished not only by use of sodium sulfide and by modifying other cooking conditions, but also by applying the recently developed principles of alkaline bleaching to the bleaching of this improved pulp. More stages of bleaching with milder conditions in each stage are required. I will discuss this a bit more in detail in a subsequent brief discussion of bleaching.

One important factor in the cooking process is the rate and extent of exhaustion of chemicals during the cooking operation. The reaction can be shown graphically by plotting the active chemical concentration against the cooking time. The initial concentration of a typical cook might be at 60 grams per liter as sodium oxide. The reaction begins on the surface lignin as soon as the liquor contacts the chips. Even before the steam is admitted to begin the cook, as much as a third of the chemical has been exhausted, and before temperature exceeds 100 degrees centigrade more than half of the active chemical is gone. During this initial period of high concentration and rapid reaction, the ready availability of the lignin minimizes the attack on the alpha cellulose, but some reaction on hemicelluloses, pentosans, and extractives is experienced.

In less than an hour of cooking time, and even before top temperature is reached, there is a rather abrupt reduction in the rate of chemical consumption. Usually more than two thirds of the active chemical has been consumed by this time. The concentration and time at which this break occurs, and its abruptness, are dependent upon the wood, the initial active chemical charge , the initial active chemical concentration, and, to some extent, the early temperature schedule of the cook.

The exhaustion of active chemicals then proceeds at a much slower rate until the end of the cook. This rate is governed by the concentration, temperature schedule, and the amount of residual unreacted lignin in the wood. The severity of these conditions also controls the selectivity of the process and the degree of degradation of the cellulosic and extractive materials. Although only limited gains in the degree of pulping can usually be gained by elongation of the cooking time because of the low chemical concentration after the first three or four hours of cooking, some extension is sometimes considered desirable so that large chips, and more resistant parts of the wood, can be penetrated and reduced to a pulpable condition.

The concentration of active chemical as modified by the buffering action of any sodium sulfide present, together with the effect of the temperature at any moment in the cook, is sometimes referred to as the reaction potential of the cook at that point. It has been estimated that, for each increase of 10 degrees centigrade in temperature, the reaction potential is doubled. The selectivity of the cooking reaction varies inversely with this reaction potential. The multitudinous sum of all these potentials throughout the cook, plus the condition of the wood, determine the yield and degree of degradation of the resulting pulp.

It would be impossible in this short time to discuss further the strength characteristics of the resulting pulps. However, I might give you a general picture of the yields. The unbleached, bone-dry yield will vary on poplar, for instance, from 48 to 52 percent, depending on the wood quality and cooking conditions. Of course, the cooking conditions are very often dependent on what the mill has as a capacity and what it requires. Thus, both maximum yield and quality are sometimes sacrificed not only for other desirable pulp characteristics but also for additional mill output. This bone-dry yield corresponds to an air-dry yield of about 1200 to 1320 pounds per cord. The heavy hardwoods have lower percent unbleached bone-dry yields, somewhere between 46 and 51 percent. That is an air-dry yield between 1470 and 1630 pounds per cord. Now I express that as an air dry yield (pulp with 10 percent moisture) because that is how most papermakers think of it. Most technical men think of yield in terms of bone-dry percent of the dry wood. However, when paying for the wood you are more interested in what you get per cord than what percent you are getting.

Class Question: (Which factor makes soda pulp so relatively weak?) I would say the big factor is the wood used. Generally soda pulp is made out of hardwoods and even the best cooking of hardwoods by any chemical pulping process makes a pulp that is not too strong as compared to pulps made from coniferous woods. By the way, some hardwood pulps are now being produced by the N.S.S.C. and kraft processes which, even though they are not as strong as many of the long fibered pulps, have better strength characteristics than were formerly thought possible. Undoubtedly, some of their poor reputation was derived from the fact that all these pulps are characteristically "tender" in the wet sheet form. It has been recently found that the dried sheets have surprisingly good bonding strength. Now that the pinch of the shortage of softwoods is being increasingly felt, many companies are looking toward this improved hardwood pulp by the modified soda and other processes to replace some of their requirements for long fibers.

Class Question: (Is pressure considered a major variable?) No. The only reason that high pressure is maintained is to maintain the temperature. Normally, soda mills maintain the pressure at only a few pounds above the saturated steam pressure. Relief is used to expel the noncondensibles such as air from the chips, the carbon dioxide which is formed during the cook, and some of the other noncondensibles which are produced. If not relieved they might create a partial pressure equal to that of the available steam so that steam could not enter the digester and carry the cook to the desired temperature. Pressure control is only an indirect method of controlling temperature.

Class Question: (Why do they no longer consider using streams in getting the wood out of the woods?) I think that in many localities paper mills are competing with industries in general for labor in the woods now. Where at one time men would work in the woods for $3.00 to $5.00 a day, they are now getting $10.00 to $11.00

per day or $1.20 to $1.30 an hour. Another factor is that there is a great loss in driving logs down the stream. You drive a stream and you get high and low water, and logs are left on the sides. It is possible to reclaim those logs but it is quite difficult. Sometimes the stream is high when you drive the logs, and it becomes low before the drive is over so that it is necessary to send a crew of men around dragging single logs for long distances to recover them. The loss is quite large and where wood is now more expensive and more valuable the losses mount up. If you lost some of them in the past, it did not make any difference because labor and wood were so cheap. This is no longer true in most localities.

Class Question: (Could you cook without peeling?) It has been found that almost all woods with bark on can be cooked by the soda process. It is not desirable, and nobody likes to do it, but it was an expedient which was very helpful during the war. Most mills have gone back to peeling. In fact, because of the shortage of woods labor, most mills that did not have peeling equipment before the war, and depended on wood being peeled in the woods, have now gone to barking drums, and whatever else they can use, to knock off that bark. It has been found economical to do that because of the amount of chemicals that are consumed by the bark in cooking, the overloaded recovery process, and the dirt content in the resulting pulp where there is competition for paper. Although there has not been any real keen competition for paper in the last few years, we expect there will be. We never did get back into the real competitive picture after the war. Everybody is looking toward peeling wood again and a lot of them are doing it. For about a year in 1948, my mill went back to all woods-peeled delivery of wood, and our dirt content dropped 50 percent. We are now cooking some rough wood.

Class Question: (Is there any severe oxidation condition caused by the oxygen entrapped in the chips contacting the hot caustic?) There is some oxidation, of course, but most of the air is removed from intimate contact with the chips before the caustic is heated to any extent. The little oxygen which remains has only a minor effect.

Class Question: (How is the wood scaled for each mill?) We have scalers who do it. Each truck and box car is scaled and inspected to see if there is any rotten wood, any crooked wood, whether the wood is within size limits, and whether there are some of marginal species. We do not like oak, or elm, but we get a little of them. There are some others that we try to hold down to reasonable limits.

Class Question: (What is the objection to elm?) Elm makes a fairly good fiber, but the reason why we object very strongly to elm is the fact that most elm grows very large and to bring in any quantity of elm, it is necessary to bring in large logs which cannot be split.

We did some experimental cooking on elm once. We brought in 12 cords. We used seven cords and had to throw the rest away. A good share of it was splinters. When we put it on a splitting axe, the axe would stall. The cross grain in elm makes it terrific to split.

Class Question: (Which do you consider the best hardwood?) There is no question about it, birch is without a doubt the best hardwood. Yellow, white, or gray are all about the same. The next best is poplar for our purposes. The Southern gum is, I would say, even better than birch in some respects. Gum is very excellent wood. Oak has some good characteristics, but it does have a large amount of extraneous materials which make it somewhat difficult to pulp.

Cooking Equipment and Operation

Let us now study the digestion equipment. The principal digestion equipment is, of course, the digester. Although a few mills have used both rotary and tumbling digesters, most mills are using vertical stationary digesters of unlined mild steel. Each digester is cylindrical in shape with conical, or dish-shaped, ends at the top and bottom.

The overall digester height is anywhere from 25 to 65 feet and the diameter varies from digester to digester from about seven to eleven feet. There are very few of even larger dimensions than this. The diameter is important other than merely as a factor which affects the digester capacity. Recent data indicate that diameters larger than about eight feet tend to cause uneven circulation and channelling of circulating liquor, especially during the beginning of the cook when circulation is important. This was found to be an increasingly serious problem as the diameter is increased. In addition, it has been found that digesters of smaller diameters generally blow cleaner than those of larger diameters. Thus, there is a trend in favor of taller digesters of smaller diameters. However, there also appear to be some maximum height limitations on stationary digesters.

The size of the digester varies depending on the designer and the needs of each mill. A multiple of units, usually three to ten per mill, is used in a scheduled series of batch operations, the number of units operated being dependent on the production requirements, the size of each digester, and the time required in each batch to produce the desired quality of pulp. Each unit may range from about 2,000 to 4,500 cubic feet in size. This gives anywhere from about five to fourteen tons of pulp per blow depending mainly on the digester size, of course, and the density of the wood used.

My particular mill is way outside those specifications because we have only little "pots" of about 805 cubic feet capacity each, which only produce somewhere around two tons per blow. Each is seven feet in diameter and about 24 feet in overall height. Ours is a small mill producing about 60 tons of pulp per day and was built around 1870. The original flanged pots were replaced with welded wrought iron digesters around the turn of the century, and the digesters have not been changed materially since that time. But I am specifying what we find generally in the industry. Our mill is definitely an exception.

Other than its general composition, size and shape, the most important feature of the digester is its method of circulating the cooking liquor. There are several types of circulation. The first, and most primitive method used, is natural circulation, which is simply caused by introducing the steam into the liquor and chip mass at the bottom of the digester. The liquor which is nearest is warmed by the condensing steam and rises by convection to create circulation until the cook reaches top temperature and additional steam is no longer needed. This method has been found to cause poor uniformity so that the pulp is degraded by local overheating near the steam inlet, and undercooked chips from dead spots in the chip mass increase the amount of screenings.

Therefore, even most of the very early mills soon had gone to the siphon type circulation. The siphonic circulation is effected by a pipe running from beneath an inverted conical perforated false bottom in the digester to a spray nozzle or head mounted inside the digester, near the top, so that siphoned liquor is sprayed over the chip mass. The steam which is introduced into the cook is injected through a nozzle into the mouth of this steam siphon pipe underneath the false bottom. The partial vacuum produced around the nozzle draws liquor, which has drained away from the chips through the false bottom, into the pipe. The force of the steam there forces the liquor up the pipe in slugs and

through the spray cap which showers it on the chips.

This is certainly superior to natural circulation. It gives considerable positive circulation during the important first part of the cook while it is being steamed. However, there is only a positive complete turnover of liquor perhaps three or four times during a cook using this type of equipment. Naturally, when most of the steam is in the cook as it approaches the top temperature, there is not enough force for any circulation for the rest of the batch.

More recent developments of the kraft and sulfite processes, intended to effect a positive circulation of liquor during the full duration of the cook, have been adopted by some soda mills. These are sometimes called "forced" or "outside" circulation systems because they involve withdrawing the liquor from the digester through a strainer at one point and introducing it again at another point using pump pressure. These systems are usually designed to turn over all the liquor in the digester about every 10 to 15 minutes, but near the end of the batch the strainer sometimes becomes plugged and the flow is often sharply reduced or even completely stopped. The plugging of the strainer is caused by a gradual realignment of the chips so that they fit into, and close, the holes in the strainer. Cooked fibers which have also broken away from chips during the process fit into the crevices and complete the seal. Steam jets are sometimes installed behind the strainer to blow these chips off, but they give only temporary and spotty improvement. However, good distribution and redistribution of chemical is effected during most of the cook with outside circulation, and a much more uniform pulp is usually produced if channelling is not experienced in the digester.

In all forced circulation systems, it is common practice to heat the withdrawn liquor before returning it to the digester. This is accomplished by two alternate methods. The first involves direct heating by introducing steam directly into the liquor through a steam injector. The other involves heating the liquor indirectly by passing it through an indirect heat exchanger. The latter eliminates the dilution otherwise caused by the direct addition of steam into the cook.

The point of exit and entrance of the circulating liquor is also varied from mill to mill. The most common method is to remove the liquor from the bottom of the digester through a perforated false bottom, or bottom strainer, and to reintroduce it into the top. The liquor can also be withdrawn from the digester through a perforated collector ring about two thirds or three fourths of the way up the side of the digester. It is then possible to reintroduce it either all in the bottom, or part in the bottom and part into the top. This last method is newer than the rest, but it is difficult to determine which system is the best for any particular installation. Any one of them can give good positive circulation at least during the beginning of the cook. It is not possible to withdraw liquor from the top of the digester because a gas cap is always left above the liquor level to prevent any liquor binding of the digester when the liquor expands as it is heated.

Control of the cook can be done by manual control of the steam and relief valves, but better systems have been applied to most installations. These controls are effected by instruments which range from a pressure reducing valve on the main steam header, and/or pressure and temperature indicators or recorders on the digesters, to pneumatically operated, cam-controlled, time schedule pressure and/or temperature controllers to accurately plot the course of each cook.

Class Question: (Why do they not use the tumbling digester if circulation is so important?) There are some advantages of good circulation in the tumbling digester. In the tumbling digester, however, the chips are dumped after the liquor is blown out through a strainer and the added expense involved in equipment to do this is not justified by the improvement which could be expected. In addition, this more complicated procedure results in more nonproductive time. Forced circulation on the stationary digester is certainly adequate for the production of pulps of maximum attainable quality by the soda process.

Corrosion in the digesters should also be briefly discussed. The lives of digesters using the straight soda process are practically unlimited. Twenty or thirty years are not considered to be long expectancies on straight soda digesters, especially those that do not have forced circulation. However, both forced circulation and the use of sulfide in the cooking process increase the corrosion problems to the point where they are actually a serious consideration in most mills that are using sulfur. Most kraft and soda digesters using considerable sulfidity last around ten and possibly twelve to fourteen years. The life seems also to be adversely effected by increasing amounts of silica in the water used in the mill, and several other factors which I will not go into right now. The amount of corrosion does vary with the process and with the water supply.

Many mills in the kraft industry have gone to stainless steel clad digesters and stainless steel digesters. Even in many of these installations, the digesters, especially some of the stainless steel clad digesters, have shown signs of pitting after short usage. Even the addition of small amounts of sulfidity have in some instances decreased the life of mild steel digesters. Experiments are now being conducted on the use of carbon brick and other special linings.

I am not going to discuss the liquor room equipment because I feel that it has more to do with the recovery process. I understand that the subject of recovery is to be covered in another lecture. However, the various liquors for cooking are usually stored in calibrated tanks in the digester house so that they can be metered into the digester being charged. There are either two or three liquors usually used. One is the white liquor, or recovered caustic liquor. The next is black liquor for reuse in the cooking process. There is some chemical left in it, and also it is used to adjust the final concentration of active chemical in the digester. A nomograph can be set up so that an operator with no technical background can use it and figure out, after he had titrated the white liquor by simple titration, how much white and black liquor are needed to get a certain initial concentration and amount of chemicals. Weak white liquor is often substituted for black liquor in this way, but they are almost never used together for this purpose. If electrolytic caustic is used as make-up for soda losses, it may be mixed into the white liquor in the storage tank, or it can be charged to the digester as a separate liquor from a separate calibrated tank. Carbonate as make-up for soda losses is normally added to the green liquor in the recovery system.

The combination of initial liquor concentration and the percentage of chemical charged on the wood determine the liquor to chip ratio. This usually varies from about 4½:1 to 6:1 on a weight to weight basis in various mills. It is considered important to charge enough liquor to cover the chips after they settle down during the first few minutes of the cook. Too much liquor will cause a liquor bound digester as the cook progresses. These are the causes of the limitations in the variation in initial liquor concentration at any particular chemical charge.

These digester liquor tanks are usually calibrated, but in many instances, instead of metering the liquor in by difference in liquid levels, it is metered in by some sort of flow meter. It is generally considered a good idea

to separate the woods to be cooked by their relative densities so that the charge of wood will not vary much from cook to cook. Then when a certain amount of white liquor is used, it will approximate a definite percent of chemical on the wood. This is at best an inaccurate method and it would be better to weigh the wood into the digester, and take its moisture content, but the approximate method is almost always used in the soda process. Heavy hardwoods are within a certain range of density. The heavy hardwoods are charged together in any single digester and so much liquor is put in; then the amount of chemical on the wood is within the weight limits required. The poplars and the cottonwoods are in another density range and the softwoods are in a third. Each group is kept separate for cooking.

In many mills, it has been found desirable to use a chip packer in charging the chips to the digester. Packing the chips involves two principles. One is the realignment of the chips so that they lie closer together, and, therefore, leaves less air spaces. This is accomplished by distributing them in the digester so they lie in flat instead of conical planes. The other is that of actually forcing the chips to settle down while they are charged by applying an external force to propel the entering chips, or to push down or shake down those charged.

The equipment used includes either a mechanical propeller, a pipe or pipes containing a series of properly directed steam jets, or a combination of the two. These are mounted in the charging hole at the top of the digester in such a way that the chips are both propelled and distributed evenly over the cross-section of the digester as they pass the packer in falling through the hole. It is possible to increase the chip load in the digester by as much as 15 or 20 percent by using a packer. A lesser degree of packing can be obtained by adding live steam to the bottom of the chip mass as the chips are being charged, or by adding the liquor to the top of the digester during the latter part of the chip charging period. The use of a packer is sometimes obviated by a design of digester which prevents clean blows when the chips are packed. This tendency is exaggerated when heavy hardwoods are being cooked.

The digester is blown by opening the blow valve which is connected to the digester at the apex of the bottom cone. A pipe line extends from the blow valve to a receptacle where the chips are broken into pulp, and the steam which flashes off is recovered or safely dissipated. The size of this valve, the size, length, and elevation of this line, the slope of the bottom cone, and the digester diameter all play their parts in determining the "blowability" of the digester. In addition, auxiliary equipment such as steam jets, or high pressure black liquor jets, are often installed in the digester for use during the blow to facilitate the removal of the stock.

The Cooking Cycle

I believe I have adequately covered a description of the digestion equipment, and I have discussed the key factors involved in the operation of the various parts and pieces. The actual cooking cycle normally involves first filling the digester, which has just been blown and opened, with chips from an overhead chip bin, or by conveyor from ground storage. The liquors are charged from the storage tanks into the charging hole or through a special connection on the digester either concurrently with, or after, introduction of the chips.

After charging of the chips and liquor is completed, the cover is fastened. The liquor circulation pump, if present, is started and the steam is manually or remote-manually turned on to start the cook. (The next digester is then prepared to blow on its prearranged schedule.) The steam can be introduced as rapidly as possible until the desired top temperature (or header pressure) is reached because, unlike the chemicals used in the sulfite or N.S.S.C. processes, sodium hydroxide ionizes to small mobile ions rather than large bulky ones. These small ions penetrate the wood very rapidly to prevent any serious polymerization of the lignin (burning the cook) which is so characteristic of what happens in the sulfite processes when the temperature is raised beyond about 110 degrees centigrade before the slower penetrating liquors have saturated the entire chip. However, some mills still find advantages in slower steaming rates, and predetermined time-temperature schedules, in cooking by the soda process.

The relief can also be handled manually or by some automatic system. Some mills have found that they can recover some heat from the relief, and some mills also reduce the pressure to some extent near the end of the cook and recover the heat in the steam which is boiled off as they relieve. Other mills have found that that is not worth the effort so they actually blow the digester from the top temperature and pressure. That is purely dependent upon the local situation.

When the predetermined cooking time has elapsed, any auxiliary blowing equipment is turned on just as the blow valve is opened, and the contents of the digester are discharged through the blow pipe to a blow pit or through a cyclonic separator for the steam into a blow tank, or into one of a number of blow pans, also referred to as washing pans or diffusers.

Blowing, Washing, and Screening

The blow pit is a cylindrical tank with a perforated false bottom, and usually has a series of baffles above to recover heat from the flash steam. When the cooked chips are blown into a blow pit, the force of the blow dashes them against a metal target plate on the opposite wall. The chips are then broken up into pulp which piles up in the pit. Water is usually showered in the baffles of the steam recovery system where it is heated for use in washing the pulp. The pulp can be then washed in the pit as in wash pans, but is often flushed out into a filter washing system.

The cyclonic separator is an inverted cone segment in shape, and the blow is introduced tangentially at its base. The steam is separated and is drawn out from the center of the base under vacuum into a series of jet and/or surface condensers in which wash water is heated by the condensing steam. The cooked chips are also broken into pulp by the centrifugal action, and the pulp and liquor run down toward the apex and discharge directly into a large cylindrical tank with a conical bottom which is installed just below the cyclone. The discharge from the cyclone might also pass through a large movable distribution pipe into one of several tanks with false bottoms called blow or wash pans (diffusers).

Washing in the pans is effected by first draining the excess black liquor which came from the digester into a storage tank which supplies the recovery system and also supplies liquor for reuse in charging the digesters and/or in flushing the pulp from them during subsequent blows. Separate tanks can also be used for each of these functions. Weak black liquor from previous washings is then showered on the pulp for a short time, followed by a draining period after which wash water is applied. Drainage of strong black liquor should be sent to the aforementioned tank until a predetermined minimum specific gravity is obtained in the effluent. The draining liquor is then shifted into the weak liquor tank for reuse in washing subsequent batches. When the effluent is clean or almost clean, it is discharged to the sewer for a short time and then the washed pulp is flushed from the pan into an intermediate storage tank. Black liquor is sent to the recovery system at 10 to 12 percent solids.

Unwashed pulp stored in a blow tank

is diluted to a regulated consistency, agitated and blended in the conical bottom, and this is pumped through a metal catcher into the first stage of a two or three stage continuous countercurrent washing system on cylindrical vacuum washers. Water is showered on the mat of pulp on the last stage cylinder. This washed pulp is then diluted and pumped to intermediate washed pulp storage. The filtrate from this cylinder is showered on the pulp on the previous cylinder. This process is repeated if three stages are employed. The filtrate from the first stage is the liquor for recovery and often contains as high as 15 or 16 percent solids. Intermediate refining of the unwashed pulp could be installed when this washing system is used, as in the high yield kraft industry, but this is not typical of soda mill operations. Rotary knotters are also sometimes used with this system on the unwashed stock.

Rotary knotters usually follow the washing system. Final unbleached screening is then accomplished with either rotary or flat screens. Normally the rotary screens have perforations of between 0.045 to 0.060 inches in diameter. The slots on the flat screens range from 0.007 to 0.012 inches in width depending on the type of pulp, and the screening process used after bleaching.

Bleaching

As I mentioned before, bleaching a chemical pulp with chlorine in the usual manner is primarily a continuation of the pulping process. Most mills that are not too interested in preserving strength in the pulp use a two or three stage bleaching system including a chlorination, possibly a high density dilute hot caustic extraction, and a hypochlorite treatment to obtain bright pulps which are very good for certain purposes, such as for a fibrous filler. However, no matter how much care is exercised to preserve maximum potential strength in the unbleached pulp, it cannot be retained after bleaching unless the pulp is subjected to the mild chemical action of a five or six stage bleach. However, some are getting some benefits from a four stage bleaching process.

Such mild conditions are much more important in the alkaline processes than in the sulfite process because in the sulfite process the lignin is in a very reactive state, while in the alkaline processes the lignin is considered to be in a polymerized state in which it is more or less unreactive to the bleaching chemicals. The more drastic sulfite bleaching conditions, when applied to alkaline lignins, result in excessive degradation of the cellulose because the higher concentration of bleaching chemicals which react slowly with the polymerized lignin are available to also react with the accompanying cellulose.

A typical five or six stage bleach would include a chlorination, a high density dilute hot caustic extraction, a second chlorination, another caustic extraction, and one or two hypochlorite stages. When rough wood is used in the pulping process, it is usually better to go to four or five stages rather five or six stages because rough wood will resist cleaning up of the dirt unless there is a more drastic treatment in the bleaching. It is necessary to sacrifice some strength here to make the pulp clean. With too mild bleaching conditions, the dirt will not be removed or sufficiently brightened in the treatment.

Another screening similar to one of those previously described can be applied to the pulp after bleaching. The final pulp is stored for use as slush in the paper mill or made into wet laps, dry rolls, or sheets for storage and/or shipment.

The bleached oven dry yield approximates 43 to 48 percent of the dry wood for poplar and 42 to 46 percent for the heavier hardwoods. This corresponds to about 1050 to 1200 pounds of air dry pulp per cord of poplar and about 1200 to 1420 pounds per cord of mixed heavy hardwoods.

Conclusion

This presents a picture of the soda pulping process. It is almost a certainty that you will never be designing a new soda mill. However, it is very possible that you will some day be supervising the operations of one of the many soda mills which are still scattered throughout this country and other parts of the world. Should this be your lot, I hope some of the thoughts brought out here will be of assistance.

Kraft Pulping

Thomas J. Carlin[1]

Graduate of University of Maine 1924 in Chemical Engineering (Pulp & Paper). Started in Kraft Pulp work on graduation and, except for 2 years (1925-1926) in the Research Department of Brown Co., was chemist and superintendent for Advance Bag & Paper Co. at Howland, Me. and Southern Advance Bag & Paper Co., Hodge, La.—until June 1944. Mill Manager for Northern Kraft Corp. 1944-1950. Kraft Mill Superintendent Brown Co., Berlin, N. H. 1950 to present time.

The Kraft Flow Diagram

It is my intention to make this talk a little easier by use of the flow sheet in *Figure 1.* It is the simplest way to picture kraft pulping and include most of the processes that take place.

The best point to start is at cooking the pulp in the digesters. We start with wood chips as the raw material and in order to convert them into pulp, we need white liquor, which I will explain later, and steam. The vertical line on the flow sheet shows the conversion of wood to brown colored pulp which we call kraft pulp. The circle, counter clockwise from the pulp washer, shows the path of the black liquor. The black liquor is converted into smelt in the recovery furnace and immediately converted into green liquor in the dissolving tank which follows. The process that the green liquor goes through to be causticized into white liquor is represented by the operations that appear in the causticizer circle. After it goes through this series of treatments it is ready to go back to the digester.

Let us consider now the general method of making kraft pulp. As noted before, in order to make a batch of pulp we need steam, wood chips, and white liquor.

Steam

The steam should be saturated and at about 135 pounds per square inch gauge. If its pressure and temperature never varied a pound or a degree one way or the other that situation would be ideal. The cooking is carried out at pressures from 80 to 110 pounds per square inch. Therefore, with the 135 pounds on the steam header to the di-

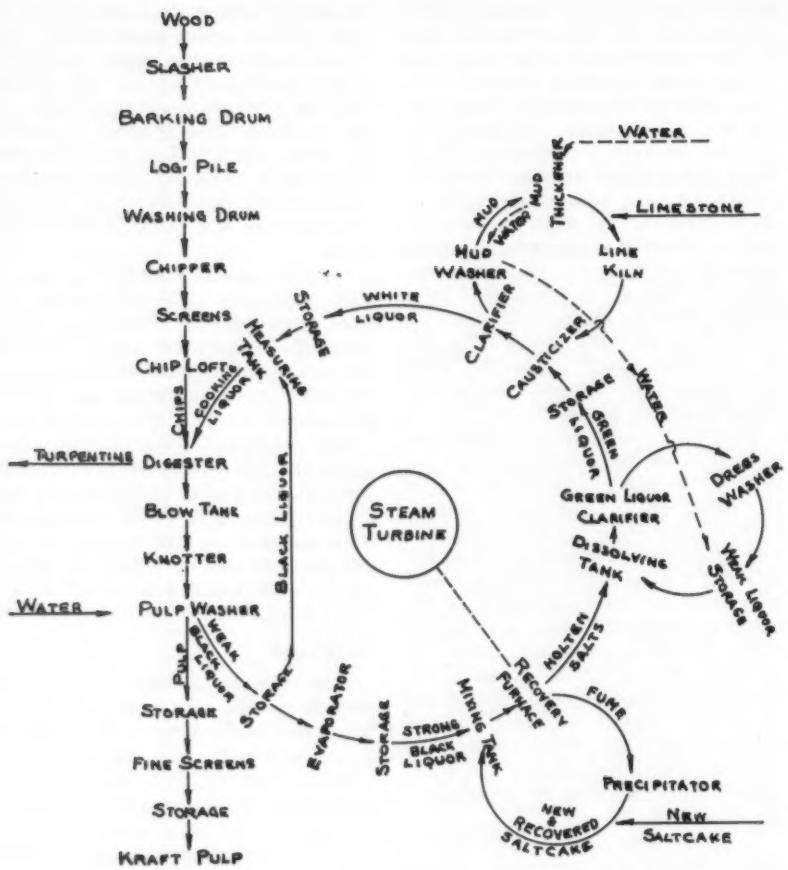

Figure 1—Diagramatic Flow Sheet of a Typical Kraft Mill.

gesters there would never be any backing up of the digester contents through the steam lines and plugging them.

Chips

In a previous paper of the series there is an explanation of how wood is processed into chips for cooking. No doubt it was explained that one cannot give too much care to this process. For the best pulp to be made at the most economical price, one must have the most uniformly sized chips that it is possible to make. For length along the grain, three-fourths of an inch is about right. This length is varied somewhat according to how long the wood has been cut and whether it is wet or dry. Oversized chips or oversized and fines mixed with a large amount of sawdust will cause considerable difficulty in cooking and a reduction in the quality of the final pulp.

The importance of having well cleaned wood, cut with a properly maintained chipper having sharp knives cannot be overemphasized. Sharpening the chipper knives at frequent intervals will more than pay its cost in better quality pulp as well as more pulp per cord of wood which, these days, is by far the largest single item in the pulp cost.

White Liquor

White liquor is the third item that should be discussed. White liquor is a mixture of sodium hydroxide, sodium sulfide, and some sodium carbonate together with a small amount of sodium sulfate. The principal chemicals and their concentration in the mill liquor are as follows (units of pounds per cubic foot expressed as sodium oxide, Na_2O): Four pounds per cubic foot for sodium hydroxide and two pounds per cubic foot for sodium sulfide. The sodium sulfide concentration is a maximum at this amount and decreases to about half of that much in mills with machinery and operating conditions where a high soda recovery is obtained.

The make-up chemical is only salt cake or sodium sulfate which yields sodium sulfide on reduction in the recovery furnace where it is reduced and smelted. The caustic soda is formed from sodium carbonate which is also made by burning black liquor in the recovery furnace. Hydrated lime ($Ca(OH)_2$) is added to the green liquor which contains the carbonate-sulfide solution and with proper mixing through agitation, the carbonate is then 80 to 85 percent converted to caustic soda. There is no action of lime on the sulfide. There will be less than one pound per cubic foot of sodium carbonate remaining.

There are about seven pounds per cubic foot, expressed as sodium oxide, of total alkali in the white liquor. That enables one to have the whole thing in the simple terms used in mill testing. The simplest way to test a solution of white liquor is to have the chemist make up standard 0.5167 normal hydrochloric acid. A one cubic centimeter of sample may then be titrated using methyl orange as an indicator. The cubic centimeters of hydrochloric acid used is equal directly to the concentration of total alkali in pounds per cubic foot. Now, in making the white liquor charge to the digester, the sodium carbonate is not considered of any cooking value. So barium chloride is added to a second sample of white liquor to precipitate out the carbonate. The clear supernatant liquor is then titrated using methyl orange and the result indicates the concentration of sodium hydroxide and sodium sulfide that comprises the active alkali. That amount will be approximately six pounds per cubic foot.

The concentration of active alkali is tested to determine the amount of white liquor which it is necessary to add to the digester for a given number of pounds of bone dry charge of chips to the digesters. The percentage by weight of active alkali on the wood is a previously determined amount.

In making this white liquor one could buy caustic soda and sodium sulfide, and mix the two together in the proportion given. Then the waste black liquor could be thrown away as it is washed from the pulp. But the cost of chemicals prohibits that. It costs so much that it is economical to purchase, install, maintain and operate the complicated recovery system to recover soda from the liquor. The kraft process has always had some sort or another of recovery system to try to get back as high a percentage as possible of the soda that was used in the cooking process.

The cooking process in the digester may be briefly stated in the following crude equation:

Chips + White Liquor
→ Pulp and Black Liquor

The pulp and black liquor are blown out of the digester and go over a heavy knot screen and then to a vacuum washer which is the separating point of the pulp and the black liquor. The pulp goes to the screens, to the paper

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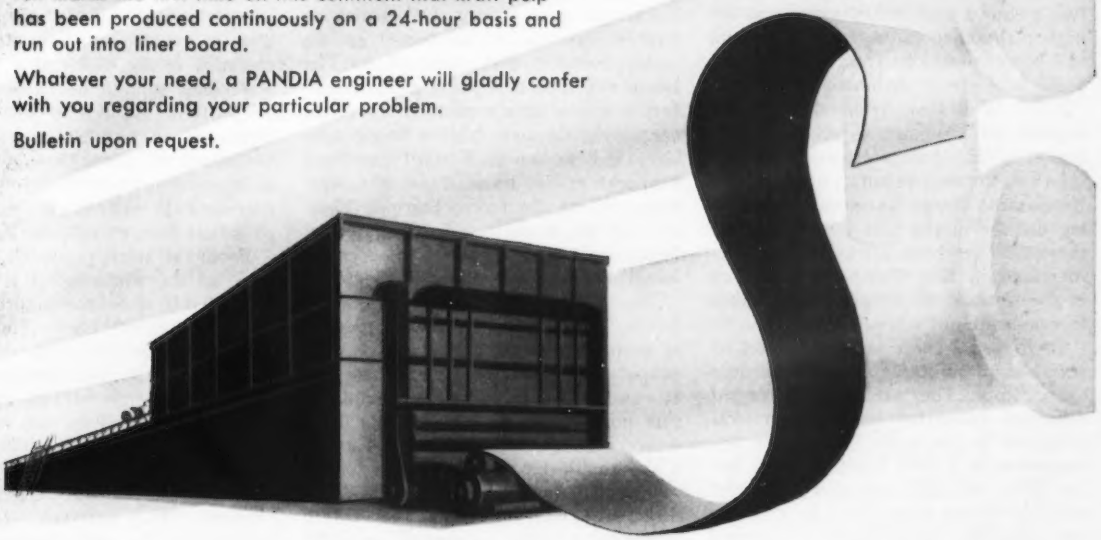

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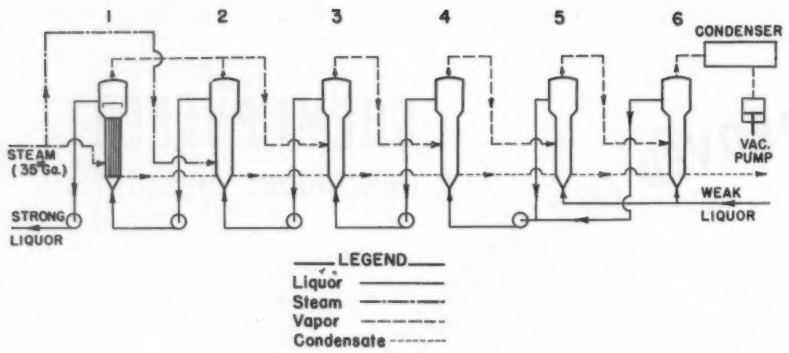

Figure 2—Vacuum Evaporators

mill and so on, whatever the process of the mill might be.

It is common practice to obtain black liquor from the screening and washing process with a density of 15 degrees Baumé.

The Recovery Cycle

Now the problem is to de-water the black liquor to a point where it has a fuel value sufficient to burn itself, to evaporate more black liquor, and produce steam and smelt. Black liquor at 15 degrees Baumé contains approximately 22.5 percent solids. In order that this black liquor will have sufficient fuel value it must be sixty percent solids when it enters the recovery furnace. It is better at 65 to 70 percent solids since the higher solids content means a higher fuel value and the higher the fuel value the more steam and power produced from the recovery boiler and steam turbine.

Now as I said, from the vacuum washer we are going to recover black liquor of 22.5 percent total solids and send it to the vacuum evaporators. Evaporator design has gone through a big change in the last few years and these changes have always resulted in increases in the efficiency. Efficiency is the amount of steam that it takes to evaporate out a pound of water.

In *Figure 2* there is shown a set of six body, quintuple effect, vacuum evaporators. They are made by several different concerns but the general principle is the same. They are arranged with a split feed, the idea being that the heat transfer is better when arranged that way. In a set of this type the weak liquor is pumped to the fifth and sixth effects. Live steam goes into the first and second effects at thirty-five pounds pressure. The evaporated steam from the first two effects goes into a common header and enters number three body, the steam goes from the number three to four, four to five, and five to six. The steam from six goes out to a barometric condenser. The water leg from the barometric condenser goes into the seal pit. The change in pressure from the first effect to the last is a graduated decrease from a pressure of about 15 pounds in the first effect to a vacuum of 26 or 27 inches of mercury in the sixth effect. The corresponding varying temperatures and varying boiling points result in practically the same amount of water evaporated in each body all the way along the line. The size of design also compensates somewhat for the increasing difficulty encountered in boiling the liquor at increasing density.

The weak liquor is pumped to the tubes. Steam outside the tubes boils the liquor and due to the design it then rises through the tubes at high velocity. It hits the cap over the top of the tube and falls into the chamber around the top of the tube section. Water vapor flashes way and is conducted to the steam chamber of the next effect. The liquor is drawn to a pump which transfers it to the tube section of the effect containing the next higher liquor density, and so on back until the final evaporation is finished in the first effect where the temperature is highest and the viscosity of the thickened liquor is low so that it can be easily handled.

The thickened liquor, or "heavy liquor," coming out of the first effect is pumped to a storage tank or disk evaporator, whatever the case may be. It contains about 50 percent solids at this point. The disk evaporator is a direct fired evaporator. It consists of a shaft with disks of steel plate spaced about two inches apart on it. The disks are so arranged that they rotate while being partly submerged in a vat of the heavy liquor. As they turn, they bring up the liquor to the section of the vat through which pass hot gases from the boiler. Some of the residual heat in the flue gases of a recovery furnace at six-hundred or seven-hundred degrees going through the turning disks will evaporate the black liquor from 50 to 65 percent. There are later developments of the disk evaporators which use steel bars and pipes instead of round disks, but they are called disk evaporators and are direct fired evaporators.

From the disk evaporators the further thickened black liquor is pumped to the recovery boiler. Most recovery units consist of two drum vertical tube boilers and have fire boxes of water-wall construction. The superheaters are mostly of the vertical tube type for ease in cleaning and lancing. The 65 percent black liquor that was produced in the disk evaporator is put in a mixing tank just before the recovery boiler and is mixed with the amount of saltcake that is needed for make up. When operation is started, a lot of saltcake is used. As operation is gradually improved, the saltcake usage is cut down. In this mixing tank, then, there is a suspension of saltcake in 65 percent total solids black liquor. That suspension is then pumped to the recovery boiler by a specially designed pump with a long packing gland because the saltcake has an abrasive action on the pump parts. This liquor is pumped through sprays into the side of the boiler or in another type into the front of the boiler but, be that as it may, it all goes to build a bed of ash in the bottom of the furnace.

There are primary air ports in the bottom of the furnace. Through these air ports hot air is blown on the side of the fire bed to keep it burning at the proper amount and keep it at the proper combustion. When there is not proper combustion there occurs what the men in the mill call a "blackout." Blackouts sometimes happen, but not very often. At a level just below the liquor spray nozzles, are located the secondary air ports through which air is injected to finish the combustion and thereby help make a maximum amount of steam through efficient burning.

From the smelt produced in the furnace all the white liquor is made that is needed to maintain the production of pulp in the mill. There is also enough steam made which, with the heat recovered from the digester blowoff steam, is enough to just about cover the steam demand for the whole mill.

The furnace gases, after passing through the disk evaporator, pass through a device called an electric precipitator. This unit removes about 95 percent of the solid matter and dust from the smoke as it passes to the chimney. In the case of the kraft process the dust in the smoke is mostly sodium salts. By this recovery a large amount of the make-up chemical is saved and returned to the process.

The recovery furnace is arranged with two spouts through which the molten sodium carbonate and sodium sulfide and residual sodium sulfate flow from the floor of the furnace to

the dissolving tank. The dissolving tank is an ordinary tank with controlled temperature of the liquor, therein. An agitator keeps the green liquor adequately stirred. One pump on the back of the dissolving tank circulates the liquor back into a spray that hits underneath the smelt as it comes out of the furnace to break up the smelt stream into fine particles.

At a start-up, the smelt is allowed to run out into the dissolving tank until such a time as it takes to build the concentration up to the seven pounds per cubic foot of total alkali which was mentioned when first discussing white liquor. When that concentration is reached the green liquor is then pumped to a green liquor storage and the operation becomes continuous. A constant level valve operates to keep the level of the dissolving tank at a desired point. As the tank is filled with water or dilute green and white liquors, the pump underneath is taking the liquor out at a concentration of seven pounds per cubic foot of total alkali. Of course the rates of pumping are such that the concentration remains constant. Mechanical, automatic instruments maintain that concentration within one-tenth of a pound per cubic foot and do an excellent job of it.

Green liquor, as it comes from the dissolving tank, contains a lot of iron hydroxide and some refractory particles which may have been burned out of the furnace. Iron hydroxide is collected from all the iron piping and tanks that the liquor goes through. These particles of solids must be separated by settling before the green liquor may be processed to white liquor. This is accomplished in the green liquor clarifier. It is simply a process of pumping the green liquor into a tank where the solids are allowed to settle. The clear liquor is drawn from the top, and the solids, or dregs as they are called, are pumped in heavy slurry form to a dregs washer to take out what residual soda there is remaining and then the washed dregs are discarded to the sewer.

Figure 3 is a diagrammatic sketch of a clarifier. This type of clarifier combines three or four trays, or sections, in one tank to obtain a maximum of efficiency in a minimum of floor space.

There is an inlet box here where the unsettled liquor comes in. From a pipe out of the bottom of the inlet box it goes into the top tray, into the top of the middle tray, and into the top of the bottom tray. Down through the center of the tank there is an agitator having very slow moving arms. The arms are very close to the bottom of each tray. When in low position the liquor going through the inlet line fills the tray completely. There is a seal at the shaft of each one. These moving arms act to draw the settled dregs toward the agitator shaft. The dregs pumps then draw these settled dregs from that point and pump them to the washers through the outlet line at the top of each tray, clear green liquor rises to another box from which it is pumped to a storage tank.

For causticizing, the clear green is pumped at a measured rate from storage to the lime slaker. A measured amount of lime (CaO) is also conveyed to the lime slaker. This all takes place continuously. The lime is slaked in the green liquor according to the following reaction:

$$CaO + H_2O \rightarrow Ca(OH)_2$$

and the mixture goes to a separator which removes any dregs or solids that react in the process and become soluble. The lime and green liquor is then pumped through three large tanks in series. Where they are thoroughly mixed by agitation to finish the causticizing reaction:

$$Ca(OH)_2 + Na_2CO_3 \rightarrow 2NaOH + CaCO_3$$

At this point the concentration of white liquor will be about four pounds of NaOH, two pounds of Na_2S and approximately one pound Na_2CO_3.

In order to convert this carbonate to caustic there is considerable precipitated calcium carbonate formed. This precipitate is removed in another clarifier exactly like the green liquor clarifier that is shown in *Figure 3*. The clarifier liquor goes to the white liquor storage tank, and is ready to be used in the digesters. The solid matter drawn from this clarifier contains the calcium carbonate which is filtered and washed on rotary vacuum filters to remove residual soda and then it is fed to the lime kiln to be calcined back to quicklime, CaO. To make up for losses in processing, new lime, as $CaCO_3$, may be fed to the kiln or new quicklime, as CaO, may be added at the slaker.

The washings from the sludge washer and vacuum filter go to a weak liquor storage and go from there to make up the liquor needed to maintain the level in the dissolving tank after the recovery unit.

Cooking

Let us assume we have stationary, up-right digesters with external, indirect heaters. Let us also assume that this digester will hold 100,000 pounds of wet chips having 50.0 percent moisture content. This gives 50,000 pounds of bone dry wood. Depending on the grade of pulp wanted, percentages of active alkali varying from 14 to 20 percent, based on the bone dry weight of woods are used. We shall use 16 percent for this cook.

The following calculations show the volume of white liquor required:

0.16 × 50,000 pounds of bone dry wood = 8,000 pounds of active alkali.

8,000 pounds ÷ 6.0 pounds cubic feet of active alkali = 1,333 cubic feet of white liquor.

This amount of liquid will not have enough total volume so that the chips will be sufficiently submerged. The required volume must be made up by addition of more liquid. This can be done with water but in line with the principle of saving all soda-containing liquors, weak black liquor is more often used. The amount needed is determined wholly by trial and error but let us assume that 2,100 cubic feet of total volume is needed. The calculation to determine the amount of black liquor to be used is as follows:

2,100 — 1,333 = 767 cubic feet of black liquor to be added to the digester.

This makes a total charge as follows:

50,000 pounds of bone dry chips.
1,333 cubic feet of white liquor.
767 cubic feet of black liquor.

The cover is then placed on the digester and tightly bolted down. The

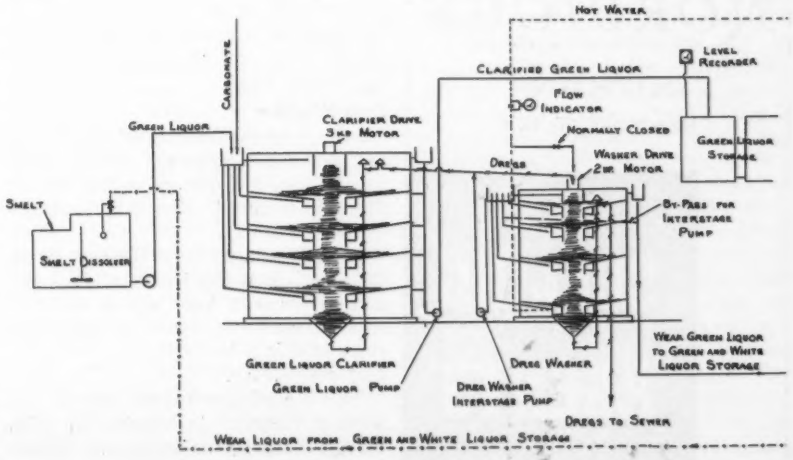

Figure 3—Green Liquor Clarification

valves to the external liquor heater are opened and the pump is started to circulate the liquor between the digester and heater. Steam is admitted to the heater at such a rate as to bring the digester to pressure of 105 pounds per square inch in the required time. Let us assume this cook is to be made in three hours by coming to full pressure in one hour. Relief of the cold inert gases is commenced when it is up to cooking pressure. The cooking proceeds at constant temperature by continuing to add steam to the heater, to make up for heat losses by radiation, for the duration of the cook. At the same time inert gas relief line from the top of the digester is left open just enough to keep the temperature of the digester contents equal to the temperature of steam at the pressure of the cook.

When cooking species of pine, the volatile turpentine evolved is removed through the digester relief line. To recover this turpentine, all vapor in the relief gas must be condensed and collected in a receiving tank. The non-condensible gases pass out to the atmosphere. The turpentine is separated from the condensed relief steam by decantation of the floating turpentine.

The steaming and relieving are thus carried on until the cook is finished. The next problem is to determine the extent to which we wish to cook the pulp. The data given so far will produce pulp in three hours. However, to have closely controlled cooking, it is advisable to run some kind of a routine hardness test on the pulp of each cook. The permanganate number is one test to use that can be performed quickly and with sufficient accuracy for the work.

When it is decided that the desired pulp has been produced we open the blow valve on the bottom of the digester and let the pulp and liquor go to the blow tank. A blow tank is a conical bottom tank having a cyclone at the top and is of a size equal to two or three times the volume of the digester in use. This tank has a bottom driven agitator which is run constantly while the tank contains any stock. The agitator can be so arranged that should the stock get too thick in it, the agitator motor drive will pull greater load or current. The increased current can be set up to actuate an automatic black liquor dilution valve to its open position and thus allow liquor to enter until the agitator motor load returns to normal. Pulp is blown tangentially into the top of the side of the cyclone. The pulp and liquor fall to the bottom and the steam goes out the top outlet to a condenser. Heat from the condensation is recovered by absorbing it in re-circulated hot water. This hot water then passes through another surface condenser to heat fresh water to be used in pulp washing and other pulp mill hot water uses.

This blow tank also acts as the pulp storage tank for the process of washing which follows.

Pulp Washing

Pulp washing consists of separating the black liquor from the pulp. This is usually accomplished on a set, usually three in number, of rotary, vacuum cylinder washers.

As it is pumped from the blow tank, the pulp is first freed from all its knots and slivers on a knot screen which is conventionally the vibratory type. The stock at this point is at about one percent consistency.

The use of the knotter screen was a step forward in connection with vacuum washer development. Knots and large chips going on the vacuum washers in the pulp sheet usually caused big black liquor spots that materially reduced the washing efficiency. The pre-knotters, so called, are small stainless steel units of the flat screen type and have perforated plates and high-speed vibrators. The pulp suspension goes through the plates and the knots are vibrated off the end to a conveyor which brings them back to the black liquor measuring tank by which means they get back to the digesters to be re-cooked.

It leaves the knot screens and flows directly to the head-box of the first vacuum cylinder. The pulp flows in sequence over the series of cylinders while liquor is removed by countercurrent washing. For example, the last cylinder spray water at about 150 degrees Fahrenheit on the pulp sheet for the final washing.

The weak liquor removed from the pulp on this last cylinder is then sprayed on the pulp on the previous cylinder. This continues on back to the first cylinder. This process makes use of the fact that pulp containing black liquor is always washed by black liquors at a lower solids concentration. Thereby, the solids are removed with a minimum of fresh water usage and this is beneficial in reducing the cost of evaporation of this water.

In old installations, washing was done by direct displacement of the liquor in the pulp by forcing the liquor out with water added on top of the pulp in a sealed tank having a screen bottom. The liquor was forced through this screen bottom until clear water was observed emerging from the pulp. This method had its advantages then. Since 1925, however, vacuum cylinder washing has been coming to the front mostly because of the labor saving advantages. Back in that time two mills in Maine installed single cylinder vacuum washers. One was on soda pulp and the other on kraft. Their use was not very successful because of the foam they caused and the poor job they did in liquor removal. Present day units of three or more stages do remove the liquor from pulp very efficiently, and operate with low man-hours per ton. They are a much more compact operating unit.

Conclusion

With the separating of the pulp and black liquor, the kraft cooking cycle is completed and ready to be repeated again. The process, with the exception of the cooking, is continuous. Even though the cooking operation is on an individual batch basis, the presence of several digesters makes it possible to keep a sufficient quantity of pulp flowing to the following operations so that cooking also may be considered continuous.

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Kraft Pulping

F. W. Brainerd

B.S. in Ch. E. from the University of Pennsylvania, 1925, and a M.S. from the Institute of Paper Chemistry, 1933. Started work in the paper industry with Dill and Collins, went to Hummel Ross and then to Scott Paper Co. in 1931. Present job is plant manager at Falls Paper & Power Co., Oconto Falls, Wis., but has had a number of others such as Staff Technical Director, and more recently Manager of Pulp Mills.

Introduction

The most interesting fact about the kraft process from the standpoint of a group of men looking forward to careers in pulp and paper is that it provides and undoubtedly will continue to provide more jobs than any other branch of the industry. In 1949, kraft production was six million tons or almost exactly 50 per cent of the industry's total of 12,150,000 tons of wood pulp. In 1929, an important year in American economic history, it was only 910,000 tons or 19 per cent of a total of 4,900,000 tons. To put it another way, kraft has contributed five million tons of a total increase of seven million tons during the past 20 years. These figures are impressive enough, but would be even more so if they included semi-chemical pulp which is being made by the kraft mills in rapidly increasing tonnages as a means of adapting hardwoods to board production. Kraft has made important progress even in dissolving pulps, the artistocracy of the wood pulp family, which until recent years were the exclusive property of the sulphite process, and the trend continues at an accelerated rate.

The explanation for this growth lies in the versatility of the kraft process. It has earned its position by its ability to use literally any kind of wood, unlike sulphite which is (or at least has been) much more selective in its requirements. The paper industry's demands long ago outgrew the available supply of traditional pulping species like spruce, balsam and western hemlock. Kraft, fortunately, has made available the vast reservoir of wood in the South and the smaller but still important reservoir of sawmill waste on the west coast which for many years went into refuse burners. New England has only recently begun to follow the pattern of the rest of the country for what are undoubtedly sound economic reasons, but elsewhere kraft provides most of the new opportunities for careers in the industry.

From the standpoint of the papermaker, kraft is not completely interchangeable with other pulps. For many years it was available only in unbleached form and as such was suitable only for board or coarse papers. Bleaching developments in recent years have made it competitive with sulphite in highgrade papers but its use is attended with some difficulties, particularly in light weight sheets. The fact that such difficulties may be due more to the characteristics of the pulpwood used as a raw material than to the process itself is of little interest to the papermaker who may look on bleached spruce sulphite as king of the papermaking fibers. The modification of kraft pulps from such woods as southern pine and Douglas fir to make them readily adaptable to all grades of paper has been and will continue to be an important field for technical studies.

The term *kraft* suggests, and properly so, that the process is of German origin. The frequently used alternative of *sulphate* is an unfortunate misnomer. Even though salt cake—anhydrous sodium sulphate—is the principal chemical purchased by the industry, it it converted under the conditions of use to a mixture of sodium hydroxide and sodium sulphide. There might be some justification for calling it the *sulphide* process but actually *kraft,* or its English equivalent of *strong,* seems most appropriate. With any given wood, kraft will in general produce a stronger pulp than any of the other commonly used processes.

Unfortunately, the name applies almost equally well to the odor. Sulphur compounds are responsible for many of the less pleasant odors found in nature and they behave no differently in industry. Progress is being made in methods of control, but odor problems are peculiarly difficult because practically complete elimination is required to accomplish a recognizable improvement. It should be mentioned in passing, however, that kraft stream pollution problems are much less severe than those faced by sulphite mills because recovery and reuse of the cooking chemical is an essential step in kraft.

Theory

Kraft is of course a close relative of the soda process. In both cases, sodium hydroxide is the active cooking agent. The only important chemical present in graft cooking liquor which is not present in soda liquor is sodium sulphide. The concentration of the latter is expressed as sulphidity, commonly defined as the ratio of the weight of sodium sulphide to the sum of the weights of sulphide plus caustic, all expressed as Na_2O. Together they make up the so-called "active alkali." For control purposes, and of necessity for green liquor which is primarily sodium carbonate, sulphidity is taken as the ratio of sulphide to the total titratable alkali, which includes besides the major components, smaller amounts of sulphite, thiosulphate and silicate.

There is as yet no unanimous agreement as to the role the sulphide ion plays. It was at one time thought that the function of the sulphide was to provide a reservoir of alkali which became available through hydrolysis to caustic soda and sodium hydrosulphide as the original charge of caustic was consumed. This delayed action was presumed to protect the pulp by subjecting it to a lower average concentration of caustic than was present in the soda process. Possibly this is a factor, but at best a minor one. Present-day thinking tends to the view that the sulphide first hydrolyzes to caustic and hydrosulphide. The latter then combines with a carbonly group in lignin to form a so-called mercapto group, slightly acidic in nature, which by its ability to react with alkali enhances the solubility of lignin in caustic. The reaction appears to progress readily in the solid phase, i.e., in chip form, for the rate of consumption of sulphide diminishes rapidly after the initial stage of cooking and before any actual pulping could have taken place.

Kraft cooking can therefore be looked upon as a two-step process consisting of an initial reaction between lignin and sodium hydrosulphide followed by solution of the reaction product in sodium hydroxide.

Even though the chemical action of sulphide may be obscure, there is no question at all about its effectiveness on an empirical basis. In quantities up to 20 per cent of the total active alkali, it increases the rate of reaction, improves the strength of pulp and reduces its bleachability. There may be some further improvement, particularly in bleachability, betwen 20 per cent and 25 per cent of the total, but the value of any higher figure is questionable. One of the newer mills in the South is operating in a range of 10-12 per cent with entirely satisfactory results. In general, the trend is downward but the subject, like papermaker's "hydration" will continue to be a fruitful source of discusion.

Sulphidity varies from mill to mill, and within the same mill for a number of reasons. In most mills the make-up chemical is salt cake which in its initial passage through the recovery furnace is converted to sulphide. The chemical recovered from the cooking liquor is a mixture of sulphide and carbonate. In effect, some sulphur has been lost in the process. Mills with high soda losses and correspondingly high make-ups therefore tend to run high sulphidity, and vice versa. A temporary condition within a mill, such as the nede for incrasing or decreasing the liquor inventory can change sulphidity correspondingly because of the change in rate of chemical feed. A precipitator on the recovery stack will reduce salt cake consumption by as much as 100 pounds per ton but it will at the same time reduce sulphidity because the chemical is recovered and re-used as a mixture of about 80 per cent sulphate and 20 per cent carbonate.

Under the wide range of conditions existing in the industry salt cake consumption may be as low as 100 pounds per ton or may exceed 300 pounds. In the lower ranges an increase in sulphidity by artificial means may be considered desirable. Sulphur is sometimes added to the cooking liquor by introducing it into the digester with the chips. It dissolves in the caustic to form sodium polysulphide which is converted to normal sulphide in the recovery cycle. Gypsum can be (but seldom is) added to the recovery furnace. It is reduced to calcium sulphide which reacts with sodium carbonate to form sodium sulphide and calcium carbonate, the latter removed subsequently as sludge. Niter cake—sodium bisulphate—raises sulphidity because its ratio of sulphur to sodium is twice that of salt cake. It is, however, a troublesome chemical to use because it is corrosive, hygroscopic and melts so readily that it tends to run through the recovery furnace into the dissolving tank where it causes a variety of troubles. Nevertheless, the mill which is now the Continental Can plant at Hopewell, Virginia, ran for some years on an accumulation of niter cake which was a by-product of a nitrocellulose operation in World War I.

Sulphidity of the actual cooking liquor is increased by the almost universal practice of adding black liquor to the digester to maintain the proper ratio of liquor volume to chips. Since the alkali in black liquor consists largely of unreacted sodium sulphide, it can increase overall sulphidity by 5 per cent or more. The actual increase varies with mill conditions and is undoubtedly of greater significance, though of course lesser in magnitude in those mills which operate at abnormally low sulphidities.

Wood preparation for kraft follows conventional lines except for the fact that cleanliness standards are less rigorous than are needed for sulphite or groundwood. The process will tolerate a certain amount of bark even in bleachable pulps. This is particularly helpful to the mill cooking hardwoods which are notoriously hard to bark except in spring and early summer. Nevertheless the highest practical degree of bark removal should be maintained because the yield is low and because it may carry sand and grit.

The chips can be larger than sulphite chips without noticeable detriment to quality and yield or increase in screenings. If there is a penetration problem in kraft it is not apparent in chip lengths up to one inch or slightly more, so this size is commonly used. As in all the chemical processes, clean, uniform chips are to be desired but their dimensions are perhaps less important than the soundness of the wood from which they are made. In the deep south, wood deterioration can be a serious problem and, during the summer months in particular, storage for more than 30 days is not to be recommended. Once decay starts, the losses in both yield and strength can be spectacular.

Cooking

The typical kraft digester is a one piece vessel of mild steel, of welded construction and tested to 150 pounds pressure. A wide range of capacities is in use but in recent years the size has tended to settle down at about 12x45 feet, equivalent to a volume of about 4000 cubic feet. This is a convenient and economical size for operation but the principal factor in its determination is that it is the largest vessel which can be handled on a single flat car. Larger sizes would require field erection unless water transportation were available. Riveted construction, almost universally used for sulphite digesters, would not be acceptable because of the possibility of concentrating caustic in the seams and causing the condition formerly called caustic embrittlement, now known as stress corrosion cracking.

Kraft digesters are not ordinarily lined. The cooking conditions are only mildly corrosive and life of 12-15 years has been considered normal. Recently, however, a number of new digesters have shown evidence of accelerated corrosion, with an estimated reduction in probable life to the range of 3 to 5 years. The problem is under intensive study but neither the chemists nor metallurgists have yet been able to advance a satisfactory explanation.

One solution is to line the digester. The choice of materials is limited, but carbon brick has been proven satisfactory. Its use does, however, result in a serious loss in digester volume which could be avoided by the use of a thinner lining such as stainless steel. A few recent applications of the latter material are being watched by the industry with a great deal of interest.

The digester should be provided with a circulating system and heat exchanger. In addition to the quality advantages which are inherent in forced circulation, such a system reduces the load on the evaporators by eliminating dilution which would otherwise result from the condensation of cooking steam. The earliest type of circulating system drew liquor through strainers in the bottom cone and circulated it over the top of the chips. More recent designs have a collector ring somewhat below the mid-point of the digester and circulate liquor both to the bottom and top at a rate sufficient to turn over the contents in 10 minutes. It is important to proportion the flows to the top and bottom approximately to the weights of wood present in the two areas because of the stoichiometric nature of the kraft process. It is, however, not necessary to go to undue lengths to distribute the liquor over the top of chips. An umbrella-shaped baffle at the pipe outlet is more satisfactory in practice than a theoretically-better perforated ring, because of the tendency of the latter to become plugged with scale and fiber.

So many of the operations which make up the kraft process have been made continuous that is is only natural to think about continuous cooking.

There are available two types of digester based on this principle, and while neither one has as yet gained anything more than a foot-hold in this country the approach is so completely logical that its eventual success seems assured. The problems are largely mechanical and of these perhaps the most important is the development of a simple, dependable seal for the incoming chips. There is a lot of potential energy stored in a digester at full pressure, and the consequences of an uncontrolled release of this energy are not pleasant to contemplate.

To return to the conventional process, the screened chips should be run over a weightometer, particularly in a mill making bleachable pulp. In the turpentine areas of the south, it is helpful also to run them under a strong electromagnet or over a magnetic pulley to remove metal such as nails and sheet iron spouts which are used in recovering gum, and which inevitably remain in the logs.

The weight of wet chips charged to the digester should be adjusted for moisture to maintain a constant dry weight. There is no completely satisfactory method for determining chip moisture, for the good methods are too slow and the quick methods are not precise enough. It is, however, essential to maintain the best possible control in order to assure a constant ratio between wood and alkali. In computing the weight of the chip charge it is customary to convert it to a basis of 50 per cent moisture because that is approximately the normal figure for green wood.

Mechanical chip packers are not ordinarily used because they require too much time. The delay represents proportionately a much greater loss of production time in the short kraft cycle than it does in the longer sulphite cycle. A substantial amount of packing, 15 per cent or more, can be accomplished by steaming the chips through the bottom cone as the digester is filled. There results some dilution which would not otherwise be present, but this is a small price to pay for the increased yield per cook.

Next the cooking chemical consisting of a mixture of white and black liquor is added through a fitting at the top of the digester. The amount varies with the type of pulp desired. In a typical mill making bleachable stock, 7800 pounds of active alkali as Na_2O are used for 25 tons of chips, bone-dry, equivalent to 15.6 per cent alkali on the weight of the wood. If the yield per digester is assumed to be 12 tons, unbleached, the alkali is equivalent to 650 pounds per ton of pulp which is the form in which the ratio is commonly expressed. For board stock the comparable figure would be about 500 pounds per ton of pulp, or about 11 per cent Na_2O on the wood.

If the active alkali content of the white liquor is 0.78 pounds per gallon, Na_2O basis, 10,000 gallons of liquor will be required for the 7800 pounds mentioned above. The total volume required for satisfactory operation of the 3900 cubic foot digester in question has been determined to be about 14,500 gallons, or about 50 per cent of the total. To make up this volume, about 4500 gallons of strong black liquor (evaporator feed) are added. No consideration is given to active alkali remaining in the black liquor, but the volume is adjusted to compensate for any excess or deficiency in chip moisture compared to the 50 per cent normal. At 50 per cent moisture, 25 tons of chips, bone-dry basis, contains 25 tons or 6000 gallons of water. The combined effect of the several measurements and adjustments

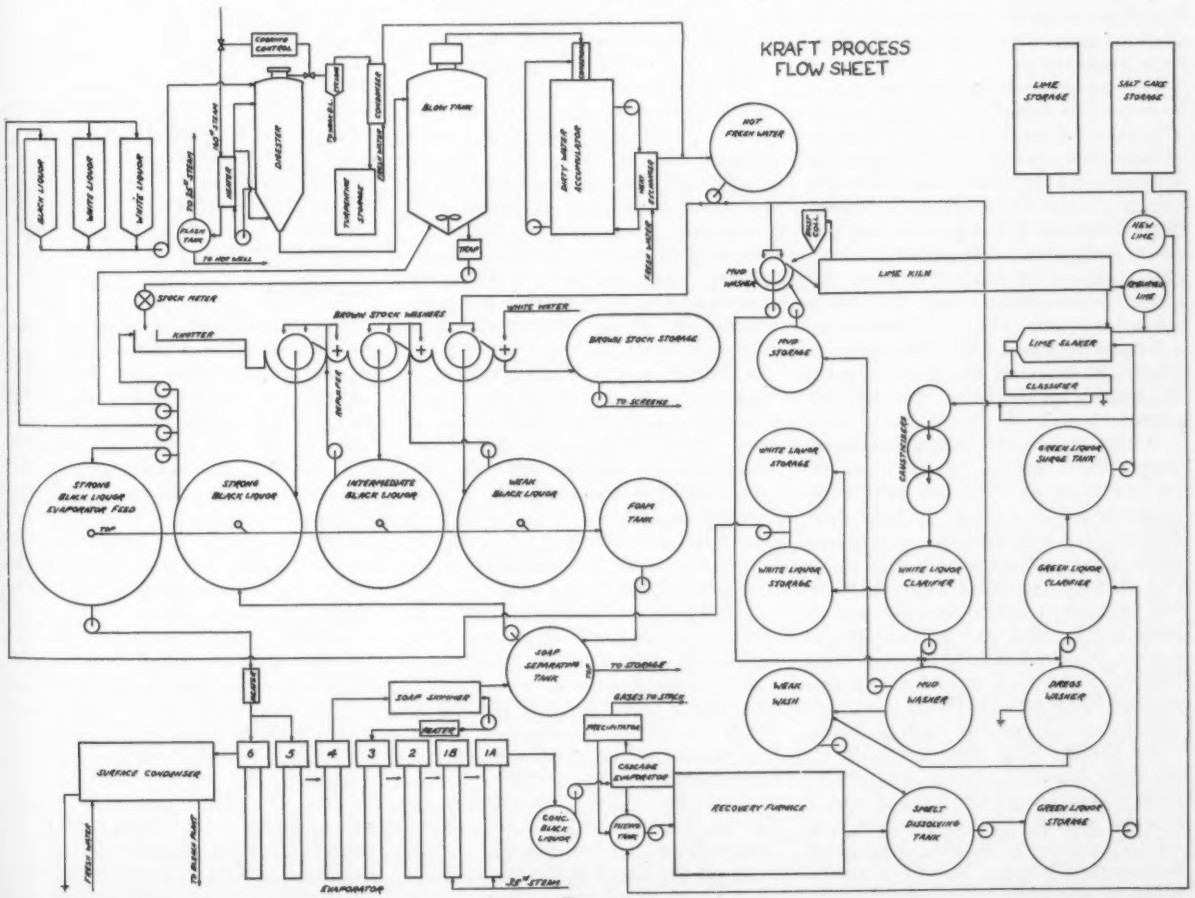

Figure 1

described above is to maintain as exactly as possible at the start of each cook a proportion of 25 tons of wood to 14,500 gallons of liquor plus 6,000 gallons of water or a total of 20,500 gallons.

It is perhaps natural to wonder if water alone might better be used than black liquor to adjust total volume, particularly for bleachable pulps where the maximum removal of non-cellulosic material is desired. A lengthy trial in the mill with which the writer is best acquainted indicated positively that black liquor dilution is preferable to water. The high proportion of sodium sulphide found in black liquor appear to be helpful, the effect on evaporator load is self-evident, and the troublesome scale problems which result from adding large volumes of hard water to a strongly alkaline system are eliminated.

The loaded digester can be brought to pressure as rapidly as the steam supply and heat transfer conditions allow. The penetration problem, which limits the permissible rate of temperature rise in lime-base sulphite mills, does not exist in kraft. There may be some slight improvement in uniformity theoretically obtainable by prolonging the period of temperature rise but the economic advantage of a shorter cook usually outweighs any such consideration.

The maximum pressure is ordinarily between 100 and 200 pounds gauge. The temperature corresponds to that of saturated steam, i.e., 338 degrees to 350 degrees Fahrenheit. It will be seen that this temperature range is notably higher than the 275 degrees to 300 degrees Fahrenheit maintained by sulphite mills. The total length of the cooking cycle varies from 2½ hours for a hard board stock of 5 hours for a bleachable pulp. Again this offers a notable contrast to the 6 to 9 hours or longer required by the sulphite process.

Within the overall limits mentioned above, there are as many types of cooking cycle as there are mills, each presumably best adapted to local conditions and requirements. Unfortunately, there will be within any given mill as many types of cycle as there are operators. Obviously only one of these can be best, and while a certain degree of standardization is obtainable by instruction the most effective way of solving the problem is to provide automatic cooking control. There are a number of systems available, all of them basically similar and all of them good. They control the steaming rate by means of a clock-driven cam which is cut to the shape of the desired temperature curve. This curve can be changed at will by substituting a new cam. Relief is controlled automatically by a separate device built around a thermostatic element which permits it to differentiate between so-called false pressure due to inert gases and true pressure which is produced by saturated steam. Such a system eliminates personal idiosyncrasies and human failings to the greatest possible extent, and perhaps even more important it puts control of the process in the hands of the technical department where it ought to be.

During the initial steaming period the digester is relieved continually to remove air plus other gases or vapors which are generated as the charge is heated. Most of the turpentine is recovered during this period. The relief, taking from the top-most point in the digester, is discharged into a cyclone which separates the entrained liquor and returns it to the recovery system. The gases pass on to a condenser and continuous decanter to separate the turpentine.

Published figures indicate a yield of 2.8 to 4.3 gallons of turpentine per ton of pulp from southern pine. The higher figure would apply only to mills in the heart of the naval stores district where the predominant species are slash and long leaf pine. At the 1950 price of 30 cents per gallon, equivalent to $1.25 per ton of pulp, turpentine represents a valuable by-product.

The conventional type of cook described above is being altered by some mills to produce a pulp of markedly different characteristics. The process is called pre-hydrolysis or more simply, pre-steaming and is based on a preliminary treatment of the chips with acid to reduce the hemicellulose content. Because the hemicellulose content of the wood is less drastically attacked by alkali than by acid it is present in kraft pulp to a greater extent than it is in sulphite and it is at least partly responsible for the unique properties, both good and bad, of kraft. Pre-hydrolysis has already extended the use of kraft into the specialized field of dissolving pulps. There is no reason to believe that it will be considered desirable in grades such as board, where strength and stiffness are of primary importance.

The process is simplicity itself. The digester is filled in the normal manner and brought to pressure with live steam. Enough natural acid is thereby produced from the wood to reduce the pH to 3.5 or less. When the digester reaches full pressure the condensate, containing in solution a large part of the original hemicellulose of the wood, is drawn off. The usual liquor charge is then pumped in and the cook completed in the normal manner. There is, of course, an appreciable reduction in yield but this is partially compensated by lower bleachability and lesser shrinkage in the bleaching operation.

The requirement for acid conditions during part of the cook of course alters digester specifications drastically. Unlined mild steel is no longer feasible nor is acid-proof brick such as the sulphite mills use because caustic attacks it. Either carbon brick or stainless steel appears to provide a satisfactory solution.

The properties of pre-hydrolyzed pulps are radically different from those of ordinary kraft. Strength factors such as Mullen, tensile and tear of the bleached pulp are reduced as much as 50 per cent, while specific volume is notably increased. The physical properties bear a strong resemblance to those of a dissolving grade of sulphite, reflecting the fact that the chemical properties of kraft have been so changed by pre-hydrolysis that it is entirely feasible to produce a quality suitable for rayon and cellophane. The tonnage of such pulps, already substantial, can be expected to increase.

Pre-hydrolysis will also lead to a wider application of southern kraft in fields which have been partly closed to it. In comparison with the better grades of sulphite, southern pine creates problems in formation, softness and printability. Its usefulness in such grades as book and soft tissues has therefore been limited. The changes wrought by pre-hydrolysis, in which a loss in strength is counter-balanced by improvements in other properties, will undoubtedly lead to a wider application of southern pine throughout the industry.

Blown Stock

Returning now to the actual process, the contents of the digester at the end of the cooking cycle are released—"blown"—at full pressure into a vessel not unlike a digester in design but large enough to hold approximately three cooks. A cyclone at the top separates entrained liquor or pulp and directs the steam to a heat recovery system. A slow speed vertical agitator extending upwards through the bottom cone keeps the pulp in suspension.

Heat recovery is important to provide hot water for other stages in the process. If a surface condenser is used, fresh water flow is controlled by a thermostatic element to produce a relatively constant temperature at the discharge. Hot water is thus made in batches which are stored in a tank and pumped away continuously as needed. If a jet condenser is used, it has been customary to supply condensing water from a closed reservoir, a

so-called "dirty water accumulator." The latent heat of the stream recovered in this manner is used to heat fresh water continuously through spiral (Rosenblad) heat exchangers.

Both systems have deficiencies of one kind or another, and at least one mill is about to return to first principles by supplying fresh water to a jet condenser and using the resulting heated water for process. This is probably the manner in which heat was first recovered from blow steam and it may well be the best.

There is released from each blow a certain amount of non-condensable vapor which can be one of the richest sources of odor in a kraft mill. The best method of disposal is to burn it in the recovery furnace by some such means as introducing it into the primary air supply, but proper precautions must be taken to prevent explosions in the ductwork connecting the condenser and furnace.

The pulp in the blow tank at about 12 per cent consistency is too heavy to pump, so it is diluted by introducing black liquor at the bottom cone in the vicinity of the agitator. It is desirable to have a trap betwen the tank and the pump, particularly in mills situated in naval stores areas, to remove tramp iron. A positive control over the volume delivered by the pump is essential at this point because the change from batch to continuous process results in a constantly varying head. Throttling devices are not satisfactory because there are always sizable pieces of wood and other materials in unscreened stock. Neither is the combination of a stuff gate and overflow, universally used in paper mills, satisfactory because the resulting air entrainment causes foam. The best method of control is to vary the speed of the pump.

Foam is a major problem in kraft mills everywhere but more so perhaps in the South because of the higher resin and fatty acid content of the wood. It has become worse since the general adoption of vacuum washers which require close attention to prevent air entrainment. In spite of foam tanks and foam breakers it can find its way out of the system. If it is directed to a sewer it represents a hidden soda loss. If it gets out in the yard it can form a shoulder-high accumulation which is an eyesore in the mill and which can be blown by high winds over considerable areas.

In modern board mills the next step is to refine the mixture of hot liquor and pulp to whatever extent is necessary to eliminate knots and uncooked chips. In mills making higher grades, particularly if the pulp is to be bleached, the pulp diluted with black liquor to 0.75 per cent consistency is run over vibrating pre-knotters of the Jonsson or Impco type. In both types of mill the purpose is the same, namely, to eliminate material which would interfere with proper loading of the vacuum washer press rolls. Efficient washing requires pressures which might damage the facing wires if knots were present. Another reason for their early removal is that they tend to settle out in the system, forming undesirable accumulations at any point where the velocity is decreased.

Vacuum washing is almost universally used to remove the black liquor. Pulp is washed counter-currently in three to five stages, preferably with repulping and dilution between stages. The washer is likely to be 8 feet in diameter and 8 to 16 feet across the fact, depending on tonnage requirements. One common specification calls for 0.75 square feet of surface per ton per day. On that basis, and 8 x 16 foot washer would have a capacity of 300 tons. One company supplies washer 11½ x 16 feet which have a rated capacity of 435 tons per day.

Hot water from the heat recovery system is added at the last stage. It is re-used counter-currently in each of the stages and the filtrate from the first washer, representing the highest concentration, is used for evaporator feed, for dilution in the digester, for dilution in the blow tank and for dilution at the pre-knotters.

A soda loss equivalent to 50 pounds of salt cake per ton in the washing system may be considered the breaking point between good and poor operation. Claims are made for losses as low a 35 pounds per ton, but they can exceed 100 pounds per ton if the system is overloaded. Soda loss is, of course, only one of the controlling factors. It could be reduced to a very low figure if water could be used indiscriminately, but since every added gallon imposes a corresponding load on the evaporators it is necessary to compromise between two important but contradictory factors. A solids content of 15-17 per cent in the evaporator feed is considered good.

Vacuum washing is relatively new. Previously wash pans or diffusers were used. They are circular steel tanks with perforated false bottoms, each sufficiently large to hold the contents of one digester. Hot water or weak liquor is added at the top and flows downward through the pulp, in wash pans by gravity, in diffiusers under pressure. Liquor emerging from the bottom is directed to evaporator feed, to weak liquor storage, or to sewer in accordance with a pre-determined schedule. Diffusers require more space than vacuum washers of equal capacity. They also offer difficulties in operation, for while positive displacement is an excellent washing principle it is impossible to maintain a truly-plug-like action throughout the cycle and so unwashed zones—"slick spots"—are not uncommon. It is doubtful that any more diffusers will be installed because vacuum washing is so immensely more satisfactory.

On the other hand, vacuum washing, which has been accepted as standard for many years may be obsolescent. One mill is using screw presses to its complete satisfaction. The stock is fed at a consistency of 11 per cent and discharged at 37 per cent, resulting in a removal of about 80 per cent of the black liquor solids in one operation. Re-dilution to 11 per cent and repressing would remove 80 per cent of the remainder, or 96 per cent in two stages, which would represent a respectable performance for multi-stage vacuum washer system. Screw presses are economical of space, not only in area but also in height because drop-legs are not needed. They also diminish very markedly the always troublesome foam problem because there is no possibility of air entrainment. Undoubtedly they bring in a new family of operating problems because the first installation in 1941 was replaced with a conventional system after the war, but it seems likely that in the not-too-distant future screw presses, possibly supplemented by a final washing stage, will occupy a preferred position.

The final step in the manufacture of brown stock is screening. All the conventional methods are in use, with the actual choice dictated by quality requirements. Centrifugal screens are widely and satisfactorily used for coarse grades but flat screens involve some difficulties because the pulp is foamy and tends to float. If the raw water is hard, the alkali inevitably present in unbleached stock causes scale formation.

Evaporation

The black liquor recovered by the washing stage will contain alkali and organic matter equivalent to about 3,000 pounds per ton of pulp at a consistency of 15 per cent to 17 per cent solids by weight. Various types of evaporators have been used over the years but current practice calls for long tube, vertical, multiple effect evaporators, usually six body quintuple effect or seven body sextuple effect. Each body consists of a bundle of small tubes, 16 to 24 feet long, surrounded by a steam jacket. This is an efficient design which takes advantage of the natural foaming tendency of the liquor to maintain a film on the

heating surfaces. Liquor is fed to two bodies in parallel at the low-pressure end, while steam is fed to two bodies in parallel at the high pressure end. Corrosion problems are fairly severe, and nickel alloys are to be recommended.

Midway through the evaporator, it is customary in southern mills to bypass the liquor through a soap skimmer. As the concentration of the liquor is increased to 25 per cent and upwards, the crude sodium soaps from resin and fatty acids present in the wood are "salted out" (to use a soapmaker's phrase) and form undesirable accumulations in the system. Fortunately, they represent a marketable byproduct; so most mills recover the soap, neutralize it with sulphuric acid and sell it as crude tallol. At the 1950 price of $50 per ton, a yield of 100 pounds per ton of pulp, represented a return of $2.50 per ton of pulp. The fatty acid component which is considered more desirable than resin acid, amounts to approximately 50 per cent of the crude tallol, somewhat less in the deep south, somewhat higher in the more northerly mills. At 40 pounds for every ton of kraft produced, the quantity of this material potentially available could make it the biggest single source of fatty acid on this continent. Purification to a point where it would be fully competitive with other oils and fats does, however, involves some difficult technical problems.

The liquor from the evaporator, concentrated to 45 to 55 per cent solids, will support combustion but it is preferably run through a cascade evaporator where it is further concentrated by heat from the recovery furnace flue gases to about 65 per cent solids.

Recovery

Today's recovery furnace, which to the layman does not appear markedly different from any other large, clean steam generating unit, represents as great a change from earlier practice as will be found anywhere in the industry. Originally kraft liquor was partially burned in rotary incinerators to black ash and then re-burned in smelters. This section of the mill was called the "black room" or "black plant," not without reason. The modern furnace sprays liquor continuously into the combustion zone where it dries, carbonizes and then drops to the floor of the furnace to be burned to a liquid ash—"smelt"—made up of the sodium salts originally present in the liquor plus any added salt cake. Simultaneously, the sulphur compounds, whether their degree of oxidation, are converted to sodium sulphide by the reducing action of the carbon formed by decomposition of the wood residues in the black liquor. A modern furnace using southern pine black liquor will produce 3½ to 4 pounds of steam per pound of black liquor solids, or 10,500 to 12,000 pounds per ton of pulp, which is well over half the total requirement for both process steam and power generation.

The flue gases carry with them soda salts equivalent to as much as 150 pounds of salt cake per ton of pulp. Unless this soda is recovered it may represent the largest single loss of chemical in the entire operation. A number of different scrubbing devices have been used, but currently electrostatic precipitators enjoy the widest acceptance. Properly designed and operated, they reduce stack losses to a negligible figure.

The final step in the process is to convert the soda salts recovered from the furnace to white liquor for re-use in the cooking cycle. The process is simple in principle but requires bulky equipment and careful control for its execution. This smelt is first dissolved to form green liquor, so-called on account of its color, then clarified to remove iron salts and unburned carbon. Quicklime is added to convert the sodium carbonate component to hydroxide, and the resulting calcium carbonate sludge is removed in continuous decanters for re-burning and re-use.

A particularly complete and lucid description of the process by R. F. Clemens (*TAPPI*, Vol. 30 1947) makes the following points concerning the functions of a re-causticizing plant:

(1) To convert as much of the recovered sodium carbonate to sodium hydroxide as possible.

(2) To produce a suitably clarified white liquor of the proper concentration.

(3) To separate, wash and de-water the lime to prepare it for calcination.

(4) To clarify the green liquor prior to re-causticizing and to wash the resulting dregs.

Summary

In summary, kraft is the newest, the largest and the most progressive of the purely chemical processes. It is particularly interesting to the chemical engineer because it uses in some form or other nearly all the unit processes which make up his particular field. Each of you must decide on a career in the near future. It would be well to bear in mind that the man who can offer a sure and certain knowledge of kraft operation plus a good record in the jobs he may have held can always be confident of a market for his talents.

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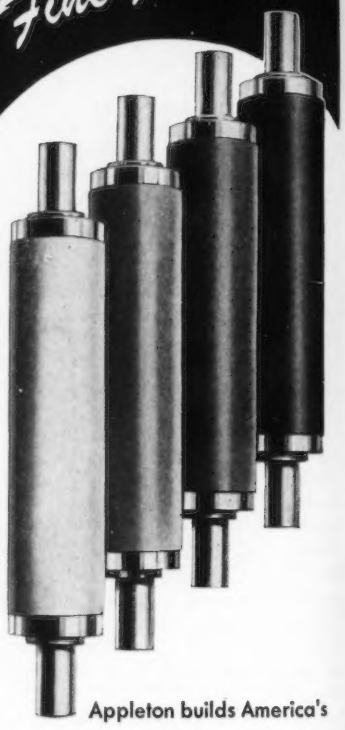

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Sulfate Recovery Units

J. H. Coulter, Jr.

Graduated from the University of Illinois with a B.S. in M.E. in 1937, and joined the Babcock and Wilcox Co. the same year. Served in the U.S. Army from 1942 to 1946, rejoining Babcock and Wilcox in 1946 as a Staff Engineer.

Foreword

The title of my lecture was to have been "Soda and Sulfate Recovery," which should have covered the miscellaneous chemical recovery operations in the mill such as the washers, multiple-effect evaporators, the recovery boiler, and the causticizers. All phases of chemical recovery are very thoroughly covered in Chapter Five of Volume One of "Pulp and Paper Manufacture" with which you are undoubtedly quite familiar.

I have taken the liberty to change this title to "Sulfate Recovery Units" for two reasons, not only do I feel unqualified to speak on three of the above four recovery operations but I also feel certain that both L. G. Willins and T. J. Carlin, whose lectures covering "Soda Pulping" and "Sulfate Pulping" respectively preceded this, have already covered these phases of chemical recovery. Mr. Carlin's lecture on "Kraft Pulping" given in the first volume of "University of Maine Industrial Lectures on Pulp and Paper Manufacture" discusses chemical recovery in general as do the papers of Messrs. Werner, Beckler, Keith, and Willins in the same lecture series.

Introduction

In the alkaline process of chemical pulping, both the soda and sulfate methods use sodium hydroxide to dissolve the lignin binder in the wood. With either, it is necessary to recover the relatively expensive sodium compounds in order to make the process commercially practical.

The flow sheet for a typical kraft mill given in *Figure 1* locates the recovery unit in the pulping process. The spent cooking liquor, known as "black liquor" which includes the dissolved lignins from the wood, is removed from the pulp on the washers. The weak black liquor contains from 15 to 18 percent solids and has a heating value barely sufficient to evaporate its water content, but if it were discarded from the process the contained chemicals and potential heating value would be lost.

The earliest type of equipment used for the actual chemical recovery operation consisted of a rotary and smelter.[1] The rotary portion consisted of a revolving cylindrical shell about 20 to 30 feet long, 9 feet in diameter, and lined with hard burned brick to a thickness of 24 inches at the inlet end and 15 inches at the discharge end, giving a slope to the inside surface. The purpose of the slope is to cause the black liquor and the resulting black ash to work gradually from the back to the front or discharge end of the revolving cylinder.

The smelter is so arranged that the hot gases from it enter the discharge end of the rotary, passing through the rotary counter current to the flow of black liquor undergoing dehydration.

At the front of the rotary the thoroughly dehydrated black liquor, or "black ash" as it is called, is discharged onto the operating platform to be mixed with the necessary salt cake, and shoveled by hand into the smelter where combustion takes place. The liberated gases rise through the smelter and pass through the rotary and to the stack while the molten smelt, consisting of the chemicals to be recovered plus a small quantity of impurities, flows through a smelter spout into a dissolving tank where it is quenched and dissolved in water or weak liquor to form "green liquor."

The rotary furnace is large and cumbersome and takes up a great deal of floor space. Rings of char form on the interior of the rotary which often dam up the flow of liquor thus necessitating hand labor to break the rings. Also, the refractory linings of the rotary and smelter deteriorate rapidly and require costly replacement.

Furthermore, rotaries and smelters are not efficient in their recovery of chemicals from black liquor. Chemical recovery efficiency usually varies within relatively wide limits, depending on control of operating conditions. Losses due to sublimation of chemical from the combustion zone and to mechanical carryover are often high. In addition, reduction of Na_2SO_4 to Na_2S is frequently low. Heat recovery, in this type of operation, is of minor importance as the primary objective of pulp mill operators is in connection with chemical recovery.

Progress has been made in rotary-smelter practice, certain of the successive steps in the developments improving both chemical and heat recovery. One of the earliest improvements was the use of a disk-type evaporator. This evaporator consists of a number of risks mounted on a shaft which rotates in a chamber in which concentrated black liquor from multiple-effect evaporators is maintained at a level corresponding to the shaft location. The disks on rotation carry liquor on their upper surfaces. The hot gases of combustion, after passing through the rotary, are led through the disk evaporator, thereby effecting the evaporation of a part of the water in the liquor. The result is an increase in thermal efficiency of the rotary furnace and a decrease in the amount of steam necessary in the multiple-effect evaporators. At the same time, these disk evaporators assist somewhat in chemical recovery, as the wet sticky surfaces of the disks in the path of the gases provide a means of catching some of the larger particles of chemicals in suspension in the gases.

The next step was the installation of waste-heat boilers, operating at a low pressure, located between the rotaries and the disk evaporators, which further increased the thermal efficiencies of the unit.

[1] The Babcock & Wilcox Co., New York 17, New York.

[1] F. W. Roberts' paper in the first volume of the University of Maine lecture series gave "The Evolution of the Modern Recovery Unit for Soda and Sulfate Pulp Mills." Volume I of Pulp and Paper Manufacture has retained from the 1937 edition of this text brief description of the older chemical recovery systems, including the early rotary incinerator and the Murray-Waern, the Ross-Wagner, and the Goodell furnaces. (For more complete description refer to "The Manufacture of Pulp and Paper", third edition, Vol. III, Sec. 5, pp 126-179, N.Y., McGraw Hill Book Co., Inc. 1937)

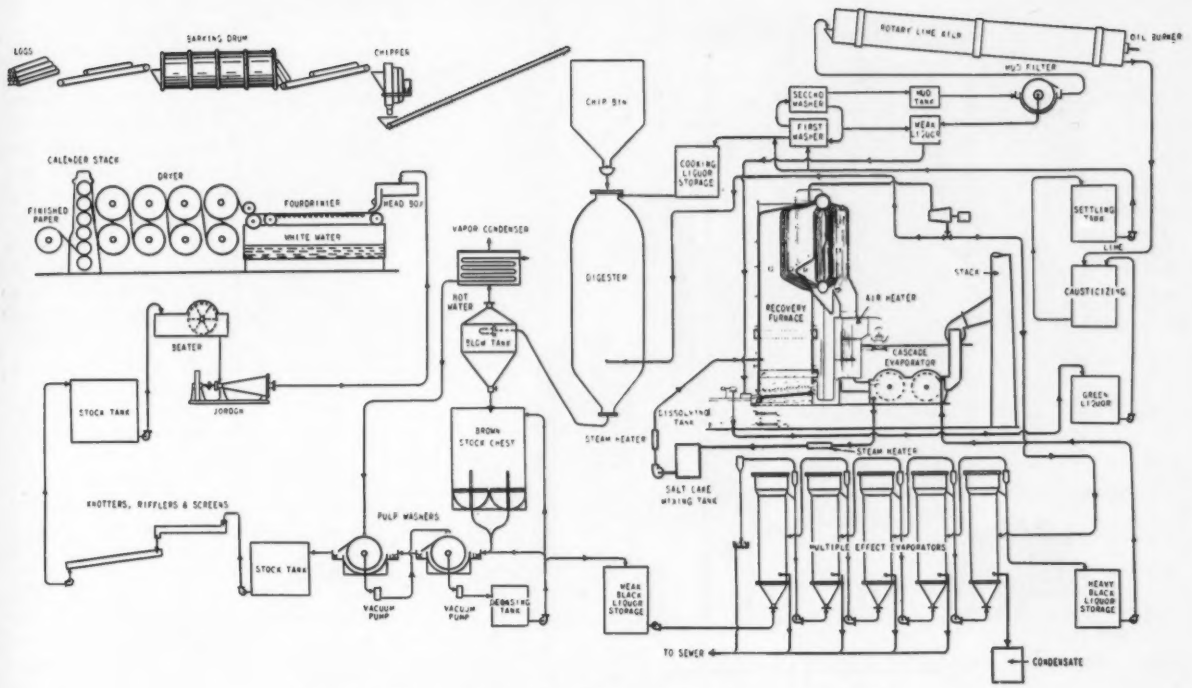


Figure I—Digrammatic Flow Sheet of Typical Kraft Pulp and Paper Mill

With all of these installations, certain important phases of combustion were very generally disregarded, and operation was conducted with high percentages of excess air in the discharge gases with attendant high heat losses. There was considerable leakage of air between the rotaries and the smelters. Where waste-heat boilers were installed, the heating-surface arrangement was not such as to give the greatest economically justifiable thermal efficiency but, rather, merely a heat trap for some heat that otherwise would be wasted.

The fuel bed in the smelter still required the closest attention. It had to be poked and rodded frequently to break up arches of caked black ash and to keep the air ports clear. Besides that, the adjustment of air supply had to be left to the judgment of the operator who relied solely on his experience with the behavior of the bed of fuel in the smelter and the quality of the blask ash. Little positive control was realized under such circumstances, and reduction as well as chemical recovery often suffered.

Development of the Modern Recovery Unit

Until 1925, the rotary and smelter comprised the sole commercial method of recovery in the industry. During that year, Charles L. Wagner of Boonton, New Jersey, introduced the first substantial advance over the rotary-smelter combination, viz., a spray type unit comprising a vertical furnace chamber within which the sprayed liquor was dehydrated and burned under self-sustaining combustion conditions. Black liquor was concentrated in multiple-effect evaporators, and steam heated concentrators, to a concentration greater than that previously employed with the rotaries and smelters, i. e. within a range of 62 and 70 percent solids. At such concentrations, the black liquor was sprayed in through a nozzle in the roof of the furnace. In falling through the furnace it was dehydrated to black ash by the rising hot gases. This formed a fuel bed of black ash in the smelter zone of the furnace where both reducing and smelting operations took place. The smelt thus formed at the bottom was then discharged through a water cooled spout into a dissolving tank.

The process constituted a decided improvement over the rotary and smelter process. With careful regulation of the spray the individual particles descended through the furnace and successively passed through the stages of dehydration and distillation while in suspension. But some of the particles burned and the ash or chemicals of these particles became entrained in the gas stream and were mechanically carried over to the boiler tube bank. Furthermore, the burning of particles in suspension prevented efficient reduction of sulfate to sulfide.

During its descent through the furnace, the black liquor must undergo virtually complete dehydration in suspension. Hence, it becomes necessary to maintain high initial solids concentration in the liquor supplied to the nozzle. The amount of suspension drying must be carefully regulated with respect to the moisture content. Insufficient drying will cause the descent of wet liquor onto the hearth and may result in a "black bottom." In that eventuality, auxiliary fuel must be supplied to quickly restore operating temperatures. However, this causes a rise in temperature which usually has the effect of increasing chemical losses due to sublimation. Excessive drying results in excessive suspension burning with resultant high chemical carryover.

Within the limitations imposed on recovery operations, due to its requiring black liquor of high solids concentrations, the Wagner process resulted in improvements in efficiency of heat utilization over that which was possible with the traditional rotary furnace combined with heat traps.

In 1928, George H. Tomlinson, then technical director of Howard Smith Paper Mills, Ltd., of Montreal, Canada, conducted exhaustive experimental work with a Wagner soda process unit at the Cornwall, Ontario, plant of his company. His investigations led to the development of a recovery unit based on an improved method of operation, i. e. spraying and dehydrating liquor on the furnace walls rather than in suspension. The first installation of a unit utilizing the Tomlinson process on sul-

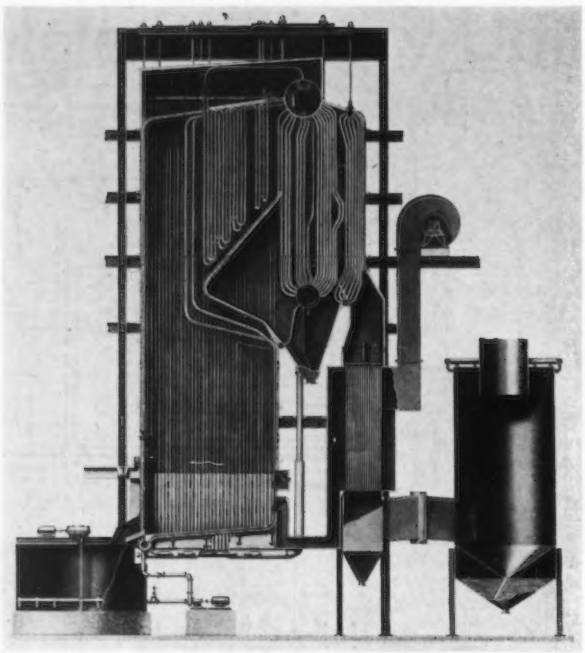


Figure 2—Modern B & W Black Liquor Unit

fate liquor was in the Windsor Mills, Quebec, plant of the Canada Paper Co. in 1929. Tomlinson subsequently built a recovery unit under a Babcock & Wilcox boiler at Windsor Mills, Province of Quebec, Canada, incorporating his improvements. In 1934, Babcock & Wilcox entered into an arrangement with Tomlinson for the development of the Tomlinson recovery process in the United States and since that date B. & W. has been actively engaged in the problem of both heat and chemical recovery in the pulp and paper industry, and the system developed is widely used by the industry. A modern Babcock & Wilcox recovery unit is shown in *Figure 2*.

Recovery Unit Operation

Referring again to *Figure 1*, to prepare the weak black liquor for incineration, it must be concentrated to a point where it will sustain combustion. The greatest part of this is done in multiple-effect steam evaporators which are usually designed to evaporate about four pounds of water from the liquor for every pound of steam consumed. Leaving the multiple-effect evaporators, the black liquor contains 45 to 55 percent solids. The liquor next goes to the recovery unit where it is further concentrated in a direct-contact evaporator to about 60 to 65 percent solids, by utilizing the sensible heat in the flue gases from the recovery boiler or air heater. Salt cake (sodium sulfate) is added to the heavy black liquor in a mixing tank to make up for all the chemical losses in the entire pulping cycle (sodium and sulfur compounds) prior to its admission to the recovery furnace. The salt cake make-up will amount to 100 to 400 pounds per ton of pulp produced, depending on a number of factors including the chemical loss from the recovery furnaces. In the Babcock & Wilcox method of combustion, two stage operation is involved in the furnace itself, due to the low-grade, high-ash, and moisture characteristics of the black liquor fuel, as well as the endothermic chemical reaction which takes place. The first stage consists of preparing or conditioning the wet fuel for combustion, and the second stage consists of the actual combustion itself.

In the first stage, the mixture of concentrated black liquor and suspended salt cake is sprayed into the recovery furnace through a special nozzle designed to produce an essentially flat sheet of relatively large particles of liquor. The liquor strikes the furnace walls where it is partially dehydrated, chiefly by radiation from the burning fuel bed in the bottom of the furnace, forming a sticky, carbonaceous "char" which builds up until it breaks off because of its own weight and falls to the floor of the furnace. Controlled distribution of liquor on the furnace walls is essential in order to obtain the desired dehydration. This is accomplished by spraying the liquor on the walls with a "paint-brush" motion. A combined vertical and rotational oscillating motion is imparted to the nozzle, such that the vertical up-and-down motion provides the "paint-brush" effect for the rear wall, and the rotational oscillation provides the same effect for the side walls. The amount of dehydration is regulated by the sweep of the oscillator which governs the area over which the liquor is sprayed and consequently the amount of drying done. The two stage furnace operation is depicted in *Figure 3*.

In the second stage, the char falls from the walls to form a bed of burning char on the furnace floor. Only a part of the air required for complete combustion is supplied to the fuel bed through the primary-air ports, since a reducing atmosphere is required to reduce the sodium sulfate and other sodium-sulfur compounds to sodium sulfide.

(1) $Na_2SO_4 + 4C \rightarrow Na_2S + 4CO$

The oxygen released in the reduction process provides part of the total oxygen required for burning the combus-

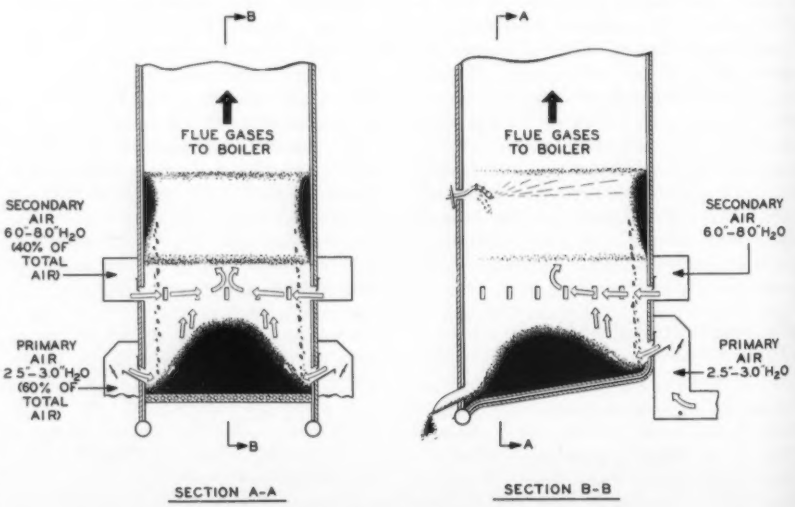


Figure 3—Two Stage Furnace Operation

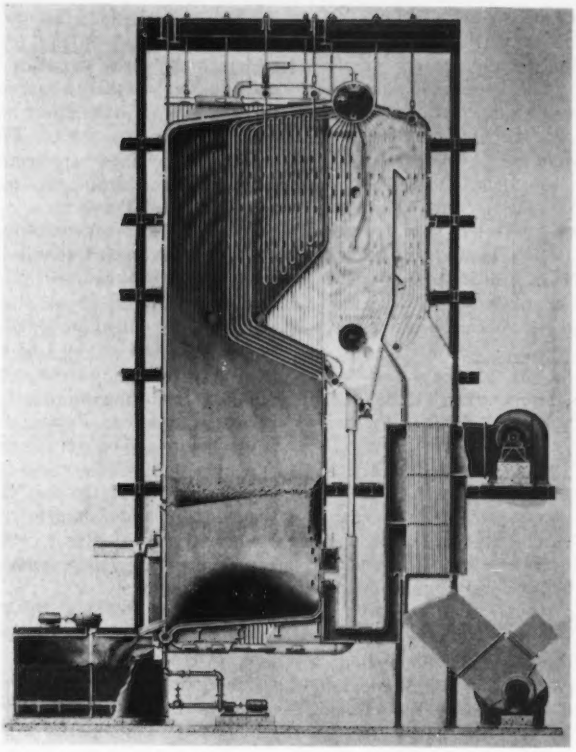


Figure 4—B & W Recovery Unit in Operation

tible constituents of the char. The heat released by combustion is sufficient to liquefy the sodium carbonate and salt cake chemicals in the char and to sustain the endothermic reduction action. The chemicals drain down the sloping floor through the porous char bed to the smelt spout where they discharge into the dissolving tank. The sodium carbonate is not affected by the reducing atmosphere, so the smelt leaving the furnace is composed largely of sodium carbonate and sodium sulfide. The hot gaseous products from the partially completed combustion of the char pass upward in the furnace, where, to complete combustion, they are mixed with additional air from the secondary-air ports located below the spray nozzle. The gases then pass through the convection sections of the steam-generating unit where the heat is reclaimed for the production of steam, thus accomplishing heat recovery as well as chemical recovery in the unit. *Figure 4* shows a sectional view of a Babcock & Wilcox-Tomlinson recovery unit, and in the drawing the artist has endeavored to depict the unit in actual operation.

A typical heat balance on a recovery boiler is given in Table I.

Table I

Typical Heat Balance on a Recovery Boiler

Input	Btu	Per Cent
Calorific value of 1 lb. of B.L. solids	6,650	97.8
Sensible heat in black liquor	150	2.2
Total	6,650	100.0
Output		
Heat absorbed by steam	4,000	60.1
Endothermic heat of reduction ($Na_2SO_4 \rightarrow Na_2S$)	250	3.8
Sensible heat in smelt	227	3.4
Sensible heat in stack gases	297	4.5
Latent heat of water in fuel	855	12.9
Latent heat of hydrogen in fuel	374	5.6
Direct evaporation in spray tower	381	5.7
Radiation and Unaccountted for losses	266	4.0
Total	6,650	100.0

The smelted chemicals drawn off into the dissolving tank are mixed with wash water from the causticizing room to form "green liquor" which is then pumped to the causticizing tank where lime ($Ca(OH)_2$) is added. The lime reacts with the sodium carbonate to form sodium hydroxide:

$$(2)\quad Na_2CO_3 + Ca(OH)_2 \rightarrow 2NaOH + CaCO_3$$

The calcium carbonate which is precipitated is then removed by settling and filtering. As the sodium sulfide is not affected by this reaction, the liquor now consists primarily of a solution of sodium hydroxide and sodium sulfide in the proportions required for the cooking liquor (white liquor)

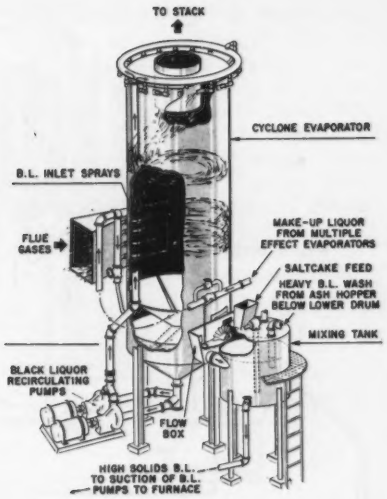

TO STACK
CYCLONE EVAPORATOR
B.L. INLET SPRAYS
FLUE GASES
MAKE-UP LIQUOR FROM MULTIPLE EFFECT EVAPORATORS
SALTCAKE FEED
HEAVY B.L. WASH FROM ASH HOPPER BELOW LOWER DRUM
MIXING TANK
BLACK LIQUOR RECIRCULATING PUMPS
FLOW BOX
HIGH SOLIDS B.L. TO SUCTION OF B.L. PUMPS TO FURNACE

Figure 5—B & W Cyclone Evaporator

charged to the digester, thus completing the cycle.

Referring again to the recovery furnace, it should be pointed out that, due to the sublimation of sodium compounds above 1700 degrees Fahrenheit it is necessary to hold a close balance between stable ignition and excess sublimation. Lower temperatures do result from the combustion of the carbonaceous material to CO rather than CO_2, and it is attempted to maintain the fuel bed temperature around 1800 degrees Fahrenheit for minimum sublimation of sodium chemicals with the resultant higher chemical recovery. Also, by keeping the bed temperatures down, the volume of gases generated in the char bed is low, hence the velocity of the rising gases is held down. Thus a minimum of particles becomes entrained in the gas stream, and the reduced mechanical carryover also means higher chemical recovery. Air is admitted over the fuel bed through the secondary air ports to complete combustion. Approximately 30 to 40 percent of the total air is admitted at this point, resulting in a gas temperature around 2100 degrees Fahrenheit. The amount of drying on the walls and the air admitted to the bed materially affect these temperatures. Reduced sublimation and low mechanical carryover, mentioned above, do result in higher chemical recovery, but of equal importance is the fact that these same items result in decreasing the cleaning requirements of the boiler surfaces and increasing the unit's availability. Even so, considerable quantities of chemicals are deposited on the tubes requiring a more intensive soot blowing schedule than would be necessary on a coal-fired job. Lance ports are placed so that all surfaces

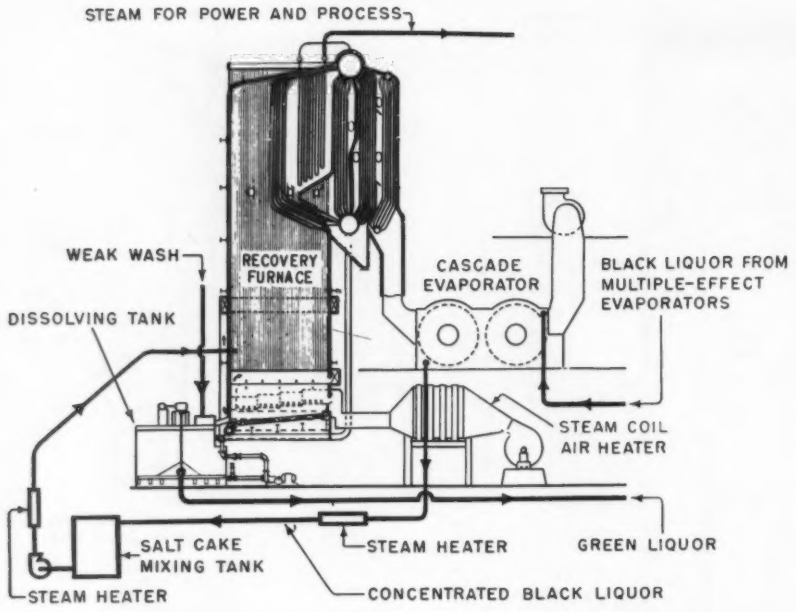


Figure 7—Recovery Unit—Cascade Evaporators to Steam Coil Air Heater

can be reached in case of an emergency.

New chemical, required to make up for the losses which occur in the various operations of the pulping process, is added in the form of sodium sulfate, called "salt cake." It is added to the black liquor in the mixing tank before it enters the furnace. You may wonder why it is that sodium sulfate is continuously added to the system as make-up and then reduced to sodium sulfide, yet the cooking liquor contains a larger per cent of sodium hydroxide than it does sulfide. In fact, most mills have difficulty in maintaining the desired ratio of sulfide to total alkali in the liquor. It is usually desired to hold this ratio, which is referred to as sulfidity between 25 and 30 percent, depending on the type of cook employed. The reason it is difficult to maintain this ratio of sodium sulfide to the total alkali is because sulfur compounds not containing sodium, such as H_2S, SO_2, etc., are lost as gases without a corresponding loss of sodium. These sulfur losses are distributed about as follows:

Digesters	3 to 8%
Multiple-effect Evaporators	48 to 55%
Recovery Room	40 to 45%

Cyclone Evaporator

In recent years, new ideas and additional pieces of equipment have been developed to supplement the recovery unit in providing more economical operation and greater chemical recovery. The direct-contact evaporator shown just after the recovery boiler in *Figure 1* is a new type of direct-contact evaporator in the form of a cyclone with a tangential gas inlet and a central gas outlet. This recent development is referred to as a Cyclone Evaporator, and is shown in *Figure 5*. Evaporation is obtained by spraying liquor into the flue gas stream at the inlet to a cyclone separator. Carryover of black liquor in the gas leaving the cyclone evaporator is eliminated by the centrifugal separation of spray drops from the gas in the cyclone. The first commercial installation went in service just five years ago and has proven quite successful. Black liquor to be concentrated is admitted through nozzles at the tangential gas inlet of the cyclone where it comes in contact with the hot gases entering. Wall-wetting nozzles, located around the periphery at the top of the cyclone, keep the wall surface, to which the spray particles may carry, continually wetted to prevent drying and charing of the liquor with resulting lump formations. These wall-wetting sprays are supplied with recirculated liquor from the reservoir at the bottom of the cyclone. It is from this same reservoir or sump that the concentrated black liquor is pumped to the mixing tank en route to the recovery unit furnace, or as shown in the arrangement of *Figure 5* the black liquor flows by gravity to the mixing tank through a flow box and is in turn pumped from the mixing tank to the recovery furnace. *Figure 6* shows the black liquor piping arrangement to the furnace with the recirculated black liquor serving as the flushing meduim to keep the boiler hoppers empty.

Other types of direct contact evaporators are the disk evaporators mentioned previously and the plate-type and tubular-type cascade evaporators which have largely replaced the earlier disk evaporators. *Figure 7* shows a recovery unit equipped with a cascade evaporator and a steam coil air heater which may be compared to the cyclone evaporator and gas air heater shown in *Figure 2*.

Fume Recovery

The flue gas leaving the sulfate black liquor recovery furnace contains substantial quantities of sodium compounds in the form of an exceedingly disperse fume, which results from the volatilization of the sodium salts in the furnace. The removal of these sodium compounds from the gas is desirable

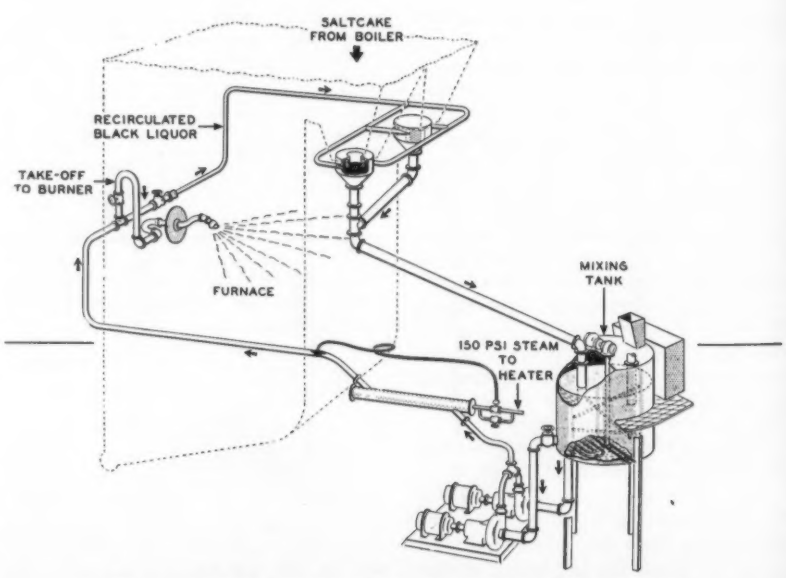


Figure 6—B & W Black Liquor Piping System Mixing Tank to Furnace

not only from a chemical efficiency standpoint, but also because it creates an industrial nuisance when discharged from the stack. Besides the sodium sulfate fume, normal flue gas contains sulfur dioxide, sulfur trioxide, and hydrogen sulfide, and under conditions where condensation occurs, rapid corrosion may result. For this reason, it has been necessary in the past to utilize dry separation methods, such as the electrical precipitator, for removing the fume of sodium sulfate from the flue gas. This results in heat losses due to the high gas temperature required, and there is no recovery of the gaseous sulfur compounds.

A successful wet separation method of fume recovery has been developed called a Venturi Scrubber which has been offered to the pulp and paper industry since 1948.

Secondary Recovery Systems

Experimental work is in progress to permit obtaining still higher efficiencies in heat and chemical recovery in the pulp mill. The pieces of equipment necessary to accomplish this, constitute the secondary recovery system, which incidentally includes the Oxidation Tower discussed later. It is not the purpose of this paper to present a detailed description of the various methods being considered to accomplish this secondary recovery. An explanation of such things as the Absorption tower, Deluge Tower, and the Venturi Scrubber, utilizing either water or black liquor, may be found in current literature on these special subjects.

It was mentioned above that, in the usual kraft mill, considerable sulfur is lost from various places in the form of gaseous compounds. The residual black liquor, after pulp cooking, contains unstable sulfur compounds such as sodium sulfide (Na_2S) and the sodium salt of methyl mercaptan (CH_3SNa). On heating, these salts hydrolize, and hydrogen sulfide and methyl mercaptan (CH_3SH) are released as gases, even in the presence of excess sodium hydroxide. In addition, the carbon dioxide in the flue gas will react with the sodium sulfide to produce hydrogen sulfide. Both hydrogen sulfide and methyl mercaptan have particularly offensive odors and are largely responsible for the unpleasant smell associated with kraft mills. In the recovery furnace these gases burn to sulfur dioxide (SO_2) and sulfur trioxide (SO_3). Ordinarily, most of these gases are lost up the stack of the recovery furnace or are vented off from the multiple-effect evaporators and digesters, with the resultant loss of sulfur. Since hydrogen sulfide is extremely corrosive, its release causes corrosion of multiple-effect evaporators, and its presence necessitates higher recovery furnace exit gas temperatures than would otherwise be required to avoid excessive corrosion of stacks, breechings, and fans.

It has been found that oxidation of weak black liquor will convert most of the unstable sulfur compounds to stable salts such as sodium thiosulfate ($Na_2S_2O_3$), and the sulfur is consequently retained in the system. Stabilization equipment to accomplish this should be located after the pulp washers in the liquor cycle, so that the stabilization of the sulfur compounds can be accomplished before the weak liquor is concentrated in the multiple-effect evaporators, where initial evolution of the hydrogen sulfide and methyl mercaptan would otherwise occur. Several mills on this continent and abroad are presently using stabilization equipment and development on this increasingly important phase of chemical loss and nuisance elimination is continuing which should eventually result in a great reduction of chemical losses, odors, and corrosion which are chargeable to the gaseous sulfur compounds emanating from various places in the mill.

Conclusion

Recovery unit development in the past seventeen years has resulted in decided improvements in both chemical and heat recovery. The greater capacity of the modern recovery unit means reduced operating labor costs and improved materials. Details of construction have resulted in much lower maintenance costs. Improved unit design has resulted in a unit which can be successfully cleaned by soot blowers and it can finally be said that the modern unit requires no routine hand lancing. The fact that the present day recovery unit, with its record of high availability, is now considered an essential part of the power generating system of the mill further emphasizes that recovery unit advancement in such a short period of time has truly been remarkable.

Chemical Recovery Unit

Vincent P. Owens[1]

Attended New York University on a Perry-McDonough-Collins scholarship and was graduated in 1934 with a BS in mechanical engineering. Received an ME Degree in 1940 for a thesis covering the development work in black liquor recovery boilers. Spent two years with Ingersoll-Rand in the refrigeration department and the Cameron Pump Division. 1934-1936. Joined Combustion Engineering Co. in 1936 and practically all his time since then has been in the Pulp and Paper mills on black liquor recovery work, wood refuse burning and steam generation. Spent four years in the Pacific Ocean area in the army, as a major.

Introduction

Two previous papers on chemical recovery units have been presented to the Pulp Technology Class. L. G. Willins, Technical Superintendent of the Sulphate Mill at the Oxford Paper Co. has presented a paper on the operation of the chemical recovery cycle. This paper includes the description of all the various phases of the chemical recovery process. Frank Roberts, the Chief Engineer of the S. D. Warren Co. has presented a paper on the chemical recovery unit giving a very thorough description of the historical background of the development of the chemical recovery units for the burning of waste black liquor and the recovery of the chemicals for reuse.

It is my intention to speak to you on one of those chemical recovery systems, the one in particular being the C. E. system which has been developed by Combustion Engineering-Superheatheater, Inc. A chemical recovery unit receives the black liquor from the storage tank after the multiple effect evaporators and discharges molten ash to the main dissolving tank in which this smelt is dissolved to form the

[1] Combustion Engineering-Superheater, Inc., Paper Mill Equipment Department, New York, N.Y.

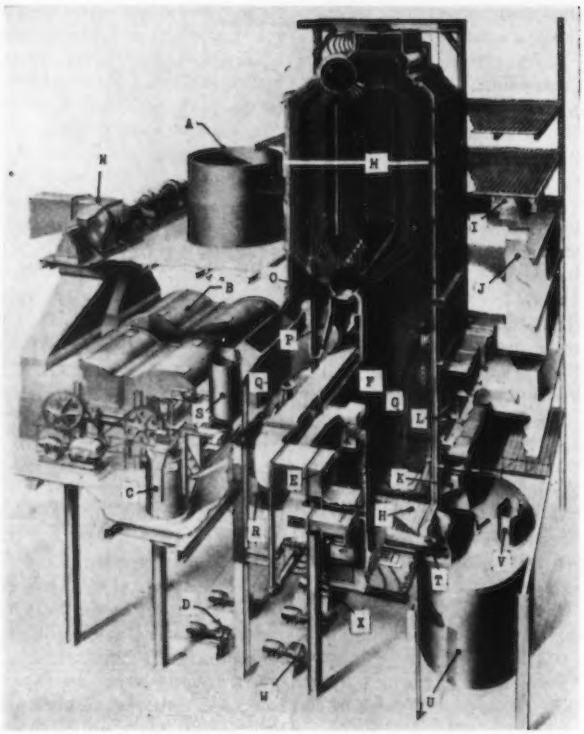


Figure 1—Combustion Engineering Co., Waste Heat and Chemical Recovery Unit. A—Head or Storage Tank, B—Cascade Evaporator, C—Salt Cake Make-Up Mixing Tank, D—Heavy Black Liquor Pump (2), E—Black Liquor Spray Nozzles (4), F—Furnace, G—Lighting-Up Oil Burners, H—Smelting Hearth, I—Forced Draft Fan, J—Steam Air Preheater, K—Primary Air Ports, L—Secondary Air Ports, M—Superheater-Boiler-Economizer, N—Induced Draft Fan, O—Economizer By-Pass Damper, P—Boiler Ash Hopper, Q—Ash Hopper Connecting Pipe, R—Ash Dissolving Tank, S—Salt Cake Make-Up Silo, T—Smelt Spout, U—Smelt Dissolving Tank, V—Smelt Dissolving Tank Vent, W—Green Liquor Circulating Pumps, X—Green Liquor Transfer Pump

green liquor. The C. E. recovery system was developed by the late F. H. Rosencrants, a Vice-President in the Engineering Department of the Combustion Engineering Co. During his lifetime, previous to starting on the work on the development of the chemical recovery unit, his engineering career was in the field of power engineering, not only from the development standpoint, but also in the design of large power stations throughout the world. In approaching the problem on the burning of black liquor from the combustion engineer's standpoint, Mr. Rosencrants was primarily interested in obtaining the best fuel for firing to the furnace by reducing the moisture in the black liquor to a minimum before spraying. For this reason he was very much interested in the cascade evaporator which concentrates black liquor to densities of between 65 and 70 percent before the liquor is sprayed in the furnace. He also was interested in a furnace and waste heat boiler suitably designed to handle the hot gases from a fuel which had, on a dry basis, an ash content of better than 40 percent, this cash content having a fusion temperature as low as 1300 to 1400 degrees Fahrenheit. Some idea of the terrific problem this particular type of fuel presents is obtained by comparing it with high grade bituminous coal. This coal will have an ash content of 5 to 8 percent and a fusion temperature of this ash of approximately 2800 degrees Fahrenheit. Thus, the problem in the design of the recovery boiler is created by the fuel high ash content, the fusion temperature of which is very low.

Functions of the Chemical Recovery Unit

The C. E. recovery unit includes the furnace, the boiler, the cascade evaporator previously mentioned, the salt cake mixing system, a heavy black liquor cycle, green liquor dissolving system, the air system, the induced draft system, the chemical ash system and also the control instruments for the operation of the recovery unit. *Figure 1* is a cut of the chemical recovery unit with letters indexed for the various component parts of the chemical recovery unit.

The functions of the chemical recovery unit are:

1. The burning of the black liquor;
2. The recovery of the chemical which is the ash content of the black liquor;
3. The addition of the sodium sulphate to the black liquor. This applies only to the sulphate not to the soda process;
4. The reduction in the furnace of this sodium sulphate to sodium sulphide.

The four functions which I have just mentioned are primarily the functions in which the pulp mill operators or the pulp mill superintendent is interested. The fifth, and another important function is the recovery of the heat that results from the burning of the black liquor. This heat, of course, is recovered in the form of high pressure steam which is used for the generation of power in the pulp and paper mill power station and also for the supply of process steam. The process steam is obtained from the discharge or the bleeding stages of the power turbines.

The following is a more detailed description of the functions of the chemical and waste heat unit in the pulp mill. This is quoted from the instruction book which our design engineers have composed for our operating engineers in the field and particularly for the purchasers' engineers and the pulp mill recovery unit operators who are responsible for the operation of the chemical recovery unit.

"In the pulp mill the modern recovery unit serves the mill in dual capacity; it provides a means of recovering the spent chemical from the black liquor that results from the digesting process and also serves as a steam generator by burning out the organic mat-

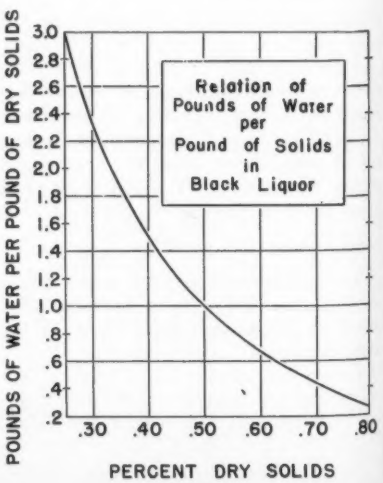


Figure 2

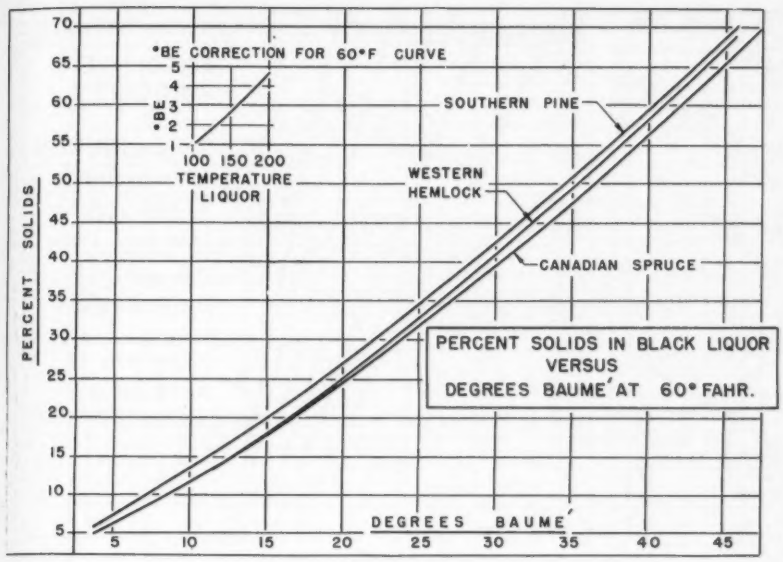


Figure 3

ter that is present in the black liquor.

The black liquor is produced as a result of the digesting action of a hot caustic solution upon wood chips in an unfired pressure vessel called a digester. After being formed in the digester, the black liquor is extracted from the cellulose fiber in the pulp washers. Immediately after the washing process, the black liquor is given the name of "weak black liquor" and usually has a water content of 80 to 85 percent, the remainder being solids and usually referred to as the solids content, or percent solids. Before the black liquor can be utilized in the recovery unit, the greater part of the water in the liquor must be removed. This is done by passing the "weak black liquor" through a set of multiple effect evaporators in which the water content is reduced to 50 percent. These evaporators are, in most pulp mills, a department in themselves and their operation is beyond the recovery unit operator's control. He should, however, become acquainted with the fundamentals of their operation as this knowledge will enable him to discuss intelligently with the evaporator operators any deviation in the solids content of the liquor supplied to the cascade evaporator of the recovery unit. Any fluctuation of liquor concentration at this point will reflect itself on the operation of the recovery unit; for instance, if the solids in the "strong black liquor" decrease from 50 percent to 45 percent, the amount of water is increased from 1.0 pound per pound of the dry solids to 1.22 pounds, or an increase of 22 percent.

Author's Note: (*Figure 2* illustrates this very clearly).

The "strong black liquor" leaving the multiple effect evaporators is pumped to the storage tank from which it is then transferred to the cascade evaporator of the chemical recovery unit. In the cascade evaporator additional water is evaporated from the black liquor by the direct contact with the hot flue gases from the outlet of the waste heat boiler which is an integral part of the recovery unit. The concentration of the liquor leaving the cascade evaporator should be somewhere within the range of 65 percent to 70 percent solids (75 percent to 80 percent true soda liquor) depending on the particular installations.

From the cascade evaporator, the concentrated or "heavy black liquor" as it is usually called, passes to the salt cake mixing tank by way of the flow box. In the salt cake mixing tank the make-up chemical, Na_2SO_4 (salt cake), is added by means of a calibrated screw feeder. This make-up chemical is required to replace the sodium salts and sulphur that are lost in the various processes of the pulp mill in addition to the chemical lost up the stack with the recovery unit flue gases.

From the salt cake mixing tank, the black liquor plus the mixed-in salt cake is passed through the black liquor heaters and is pumped under pressure to the black liquor sprays through which it is finally introduced into the furnace where it is dried and burned.

During the burning process the ash that is contained in the black liquor is melted and is drained from the furnace bottom through the water-cooled troughs called smelt spouts. The ash consists entirely of sodium salts, excepting a very small percentage of impurities, and in its molten state is usually spoken of as smelt. The sodium salts are all water soluble, so the molten smelt is quenched and dissolved in a tank equipped with some means of agitation. This tank and its agitating equipment is spoken of as the main dissolving tank.

Once the smelt has been dissolved in the main dissolving tank, the resulting solution is called green liquor; it is, given this name because of the dark green color that the liquid has at this point. After the liquor has dissolved enough of the sodium salts to give it the desired concentration, it is transferred by a pump to the causticizing room where it is processed by the addition of calcium hydroxide to convert the sodium carbonate present into sodium hydroxide. After the solution containing sodium hydroxide plus the remaining sodium salts has ben clarified, it is spoken of as white liquor and is ready to be pumped back to the digester where it will be used once again in the digesting process of the raw wood chips."

Properties of Black Liquor

Since the recovery unit is equipment for the combustion of black liquor, a brief discussion of the characteristics and properties of the black liquor is worth while. In the recovery room, the first and most important thing in which the operator is interested is the density of the black liquor that he receives from the multiple effect evaporators. This density is obtained by hydrometer. On *Figure 3* are plotted curves which give the relationship between the hydrometer reading in degrees Baumé and the percent solids contained in the black liquor. This shows the relationship for Southern pine liquor, Canadian spruce liquor, and the black liquor from Western Hemlock.

For the same Baumé, the Southern pine liquor has a slightly higher percentage solids than either the Canadian spruce or Western hemlock liquor. This, of course, is important to equipment manufacturers building recovery units for various parts of the United States and, for that matter, various parts of the world, because the basis of our design, the basis of operation, and the resulting steam flow that you will obtain from chemical recovery depends upon the density of the liquor that is fed to the chemical recovery unit. As previously mentioned, the curve on *Figure 2* shows the relationship between the pounds of water per pound of dry solids and the term of "percent dry solids," which is normally used in the discussion of black liquor. Thus 50 percent solids means that 50 percent of the total weight of the black

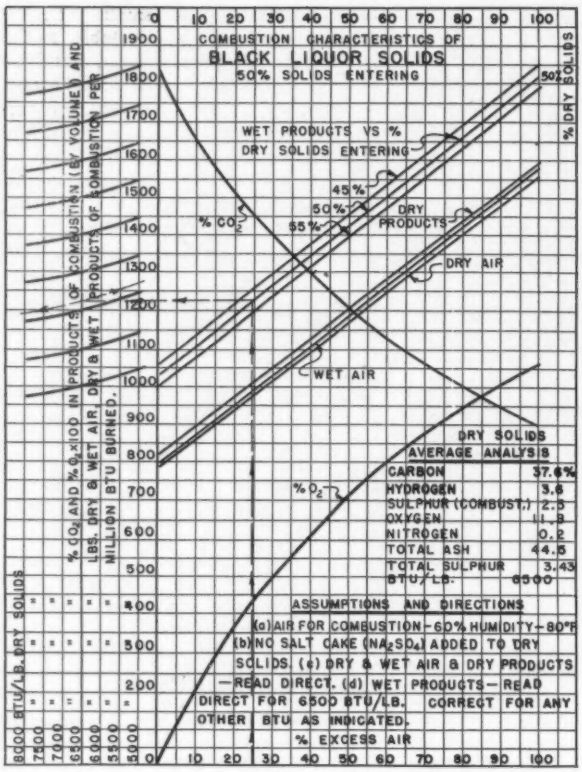

COMBUSTION CHARACTERISTICS OF
BLACK LIQUOR SOLIDS
50% SOLIDS ENTERING
WET PRODUCTS VS % DRY SOLIDS ENTERING
45%
50%
55%
DRY PRODUCTS
DRY AIR
WET AIR
% CO_2
% O_2
% DRY SOLIDS
DRY SOLIDS AVERAGE ANALYSIS
CARBON 37.6%
HYDROGEN 3.8
SULPHUR (COMBUST.) 2.5
OXYGEN 11.3
NITROGEN 0.2
TOTAL ASH 44.5
TOTAL SULPHUR 3.43
BTU/LB. 6500
ASSUMPTIONS AND DIRECTIONS
(a) AIR FOR COMBUSTION - 60% HUMIDITY - 80°F
(b) NO SALT CAKE (Na_2SO_4) ADDED TO DRY SOLIDS. (c) DRY & WET AIR & DRY PRODUCTS — READ DIRECT. (d) WET PRODUCTS — READ DIRECT FOR 6500 BTU/LB. CORRECT FOR ANY OTHER BTU AS INDICATED.
% EXCESS AIR
LBS. DRY & WET AIR, DRY & WET PRODUCTS OF COMBUSTION PER MILLION BTU BURNED.
% CO_2 AND % O_2 AND % MOD IN PRODUCTS OF COMBUSTION (BY VOLUME)
8000 BTU/LB. DRY SOLIDS
7500
7000
6500
6000
5500
5000

Figure 4

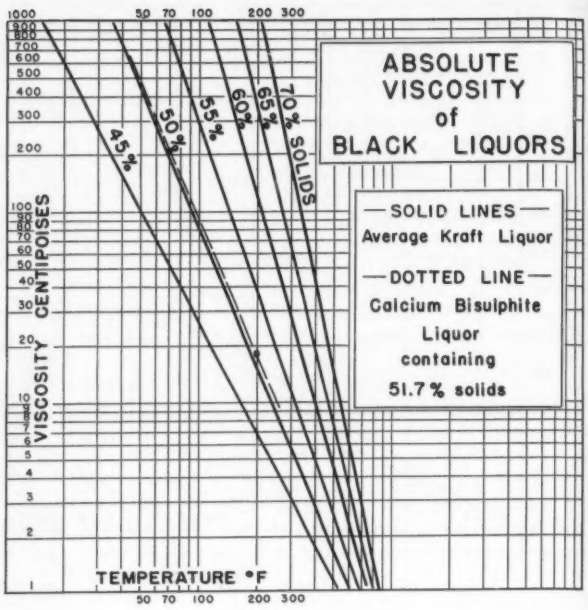


Figure 5

liquor is the dry material. *Figure 4* is a combustion characteristic curve for black liquor. Also shown is the BTU per pound of dry solids. These figures are normally used in the design of chemical recovery units. The heating value of black liquor will vary from as low as 6000 BTU per pound to as high as 7000 BTU per pound and even higher. In a mill which is making a bleaching pulp from hardwoods, the chemical charge is comparatively high. The ratio of the inorganic to the organic matter in that dry solids becomes higher and the resulting BTU value is lower. In a mill that is making a brown stock, the chemical charge is comparatively low and the BTU value will run as high as 7000. In our experience with the Finnish mills, we find that the heating values are running as high as 7300 BTU per pound.

The difference in BTU is important. In the first place, when the BTU is low, the problem of burning becomes more severe. The resulting furnace temperatures are much lower. Stable furnace conditions are required for a good, normal, trouble-free operation of the chemical recovery unit. Chemical recovery units designed for high heating value must include greater heat surfaces to produce the higher steam flows and reduce the exit gas temperatures. Even though only the average analysis of the black liquor is listed here, it is important in the design of recovery units to know the exact analysis of the black liquor to be burned and also the exact heating value.

Figure 5 shows the viscosities of black liquor for various densities and for various temperatures of the black liquor. The temperature of the black liquor has great effect upon the resulting viscosity of the black liquor. In the operation of the cascade evaporator and the recovery furnaces, the operator should endeavor to obtain the highest concentration of black liquor from the cascade evaporator. He is limited in this concentration by the viscosity and the resulting pumping characteristics of the black liquor. Normally with sulphate black liquor he is able to concentrate to between 65 to 70 percent solids, depending upon the viscosity of the liquor.

The black liquor obtained from the soda process has a comparatively lower viscosity than that from the sulphate process. In the soda units which have been operating at the S. D. Warren Co. and the Oxford Paper Co., it is possible to pump the black liquor at concentrations of 80 percent solids. This 80 percent solids for soda liquor corresponds to the same viscosity as sulphate black liquor at about approximately 67 percent solids. This relationship is favorable in the operation of the soda unit because the smelting characteristics of the soda ash are more severe than the smelting characteristics of the sulphate ash. The fusion temperature of the soda ash is higher than that of the sulphate ash. For this reason, it is necessary to have slightly higher furnace temperatures. By operating with the higher concentration of the soda liquor, higher furnace temperatures are obtained, thereby providing better and more uniform smelting conditions in the recovery furnace.

These combustion characteristics curves, *Figure 4,* show the required weights of air and the resulting weights of gases which are computed from the combustion reaction formula for the various components of the black liquor, the carbon, the hydrogen and the sulphur. With this curve, it is possible to determine readily for any CO_2, the percent excess air, and weight of the air required and gases resulting from the combustion. These curves plotted for black liquor are similar to curves for any type of fuel. In the design of furnaces and boilers, these combustion characteristics curves are handy references and avoid the long and complicated calculations that would otherwise be followed to determine air and gas weights. The combustion characteristics curve is also of importance in plotting back the performance of any particular boiler. By determining the CO_2 with an Orsat apparatus, and referring back to the combustion characteristic curve, it is possible to determine the weight of gases that are being produced by the combustion.

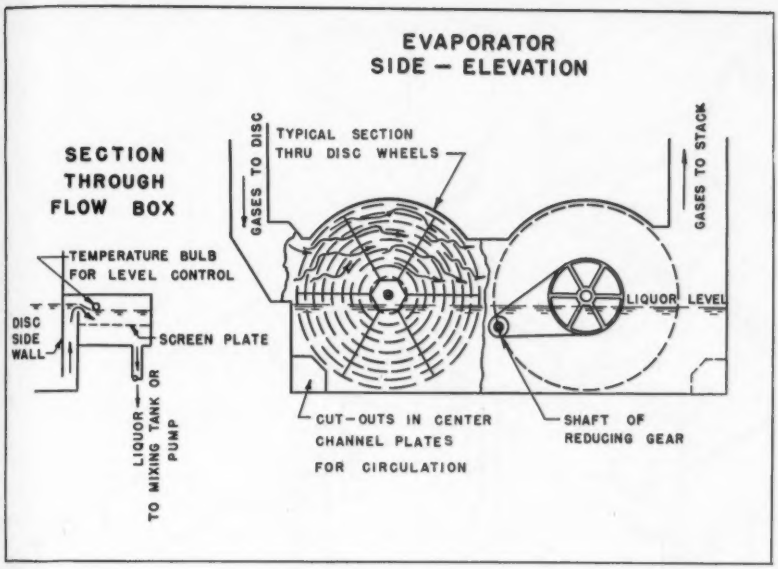


Figure 6

Heavy Black Liquor Cycle

The heavy black liquor cycle which is considered to be that section between the cascade evaporator and the recovery furnace and is the most important section of the chemical recovery unit. The functions of the black liquor cycle are:

1. The evaporation of the black liquor in the cascade from 50 percent to 65 to 70 percent solids;
2. The mixing of make-up salt cake;
3. The heating of the black liquor. The black liquor leaves the cascade evaporator at an average temperature of 195 degrees Fahrenheit. In the primary liquor heaters between the cascade evaporator and the black liquor pump, the temperature of the black liquor is raised to approximately 200 degrees Fahrenheit. This five degrees difference in temperature cuts down on the viscosity of the black liquor and makes the pumping of the black liquor easier. The secondary heater adds the additional heat to obtain the desired spray temperature;
4. Pumping;
5. Spraying;
6. Controlling of the liquor level in the cascade to give a uniform flow of the quantity of black liquor and the controlling of the temperatures of the black liquor to give a uniform temperature of the of the black liquor sprayed to the furnace.

The functions of a cascade evaporator are:

1. The recovery of waste heat from the flue gases. With the evaporation of water from the black liquor the temperature of the gases of combustion is reduced and, in doing this, the cascade evaporator is actually acting as a heat exchanger and a piece of heat recovery equipment.
2. The scrubbing of the gases. The cascade evaporator will remove from the gases of combustion those particles of chemical which are bigger than approximately one micron. The combustion of black liquor generates a larger quantity of sodium salts that are formed by the sublimation of the chemical in the furnace. These particles are fractions of a micron in size and are not picked up by the cascade evaporator. However, the carry-over that results from the spray which are particles bigger than one micron are picked up by the cascade evaporator.

Figure 6 shows the cross section of the evaporator. Normally the evaporator is built for the larger size machines, with four wheels, two of which are in parallel and two of which are in series. The cascade evaporator contains black liquor up to a level of two or three feet below the center line of the shaft. These wheels revolve in this bath of liquor. The surfaces are wetted and travel up through the hot gases. The hot gases in passing over the wetted surface evaporate the moisture. When the dry surface passes down through the liquor, that dry substance is washed off and mixed with the liquid. The turning of the wheels acts as a mixer and also as a pump for the circulation of black liquor with-

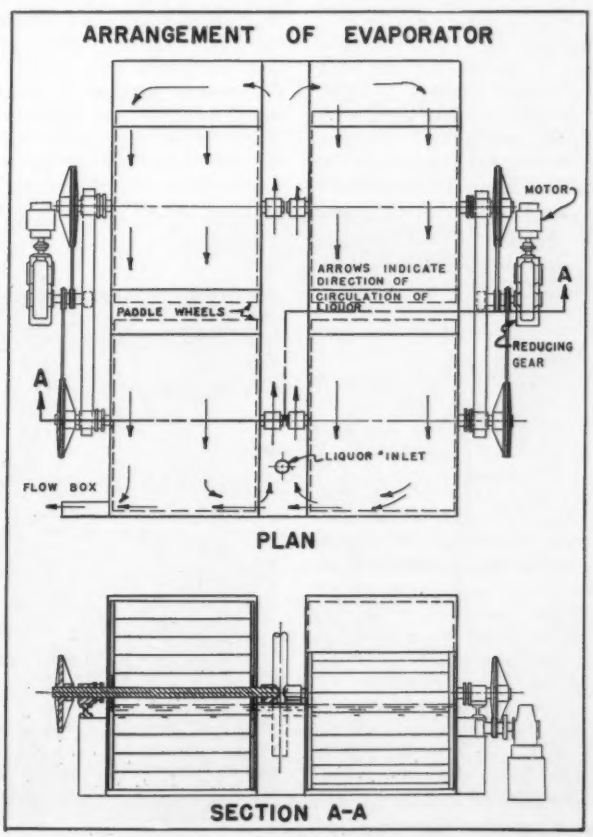


Figure 7

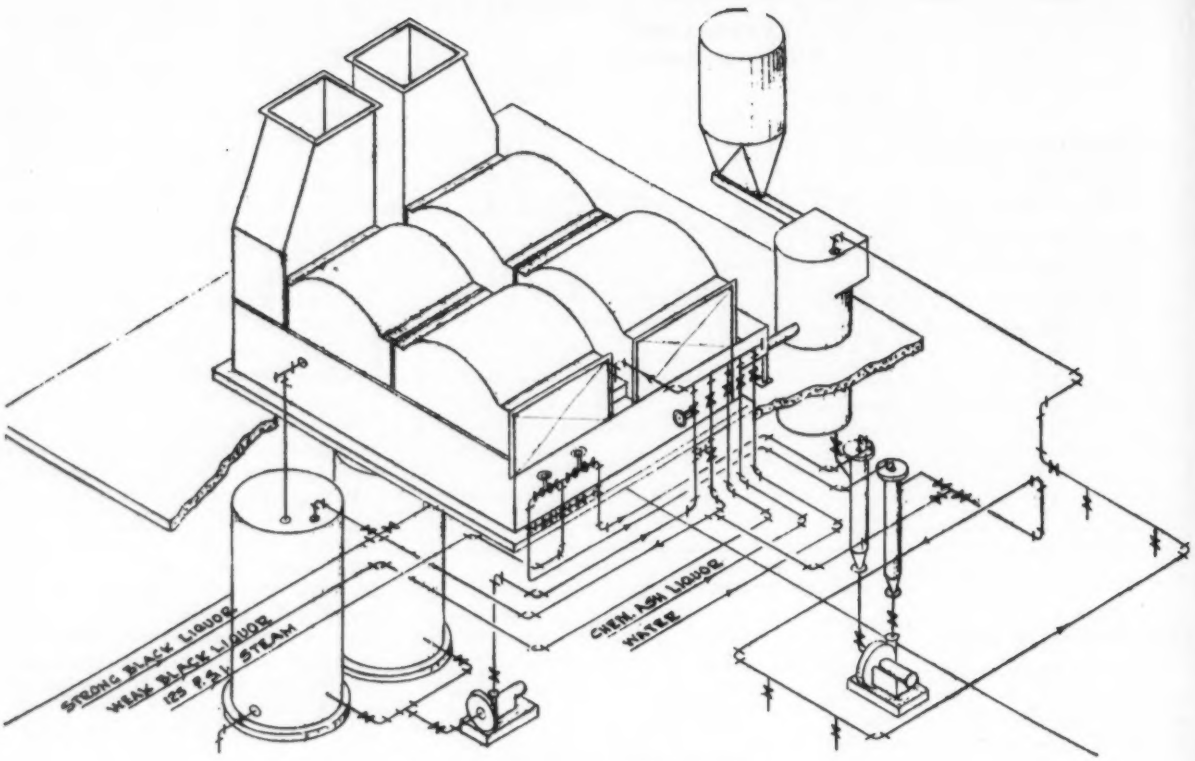


Figure 9—Arrangement of Black Liquor Piping

in the cascade evaporator. *Figure 7* indicates circulation under the wheels in the direction of the turning and back through the center channel to again pass under the wheels. The weak black liquor from the multiple effect evaporator enters in the center channel. The wheels mix the liquor into a uniform consistency so that the black liquor taken from the lower left hand corner, as shown, is of a uniform density.

The plate type evaporator has been in use for 15 years or more. The late W. A. Waern is responsible more than any other individual for the development of this evaporator. In *Figure 6,* the straight black lines indicate the plate surfaces. When the hot gases hit the plate surface shown in this cascade evaporator, their direction is turned 90 degrees. The gases then make another right angle turn to pass over the plate in the next row. The back of the plate is not very thoroughly scrubbed by the gases. When tubes are substituted for plates, the gases passing over the tube hang snug to the tube and in doing so, make the entire surface area of the tube effective heat transfer area.

Figure 8 is a photograph showing a tubular surface cascade evaporator. The tubular type wheel was developed about 1942 by Charles Smith of the Central Paper Co. The advantages of the tubular type wheel are two-fold. In the first place, as mentioned previously, a more effective scrubbing of all the surface on that tube is obtained so that the overall heat transfer rate for the tubular surface is greater. Secondly, more tubular surface can be installed in the same diameter wheel. In one case where a plate type wheel was converted to a tubular type, the original plate wheel had 2800 square feet, and the new tubular wheel had 3400 square feet.

The temperature drop that is required in the cascade evaporator is determined from the amount of evaporation work that has to be done. The heat removed from the hot gases is equivalent to the heat that is required for the evaporation of the black liquor

Figure 8

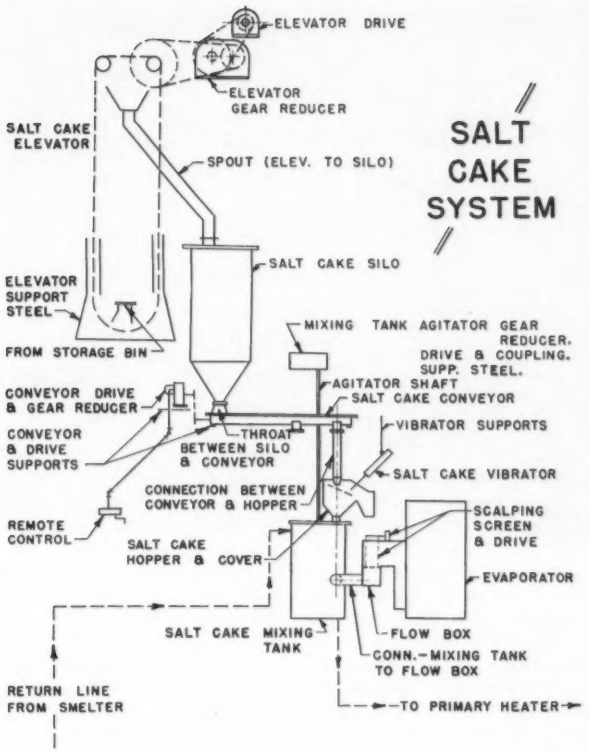


Figure 10

in the cascade, plus a slight radiation loss. The wheels of the cascade turn five revolutions per minute. Because the tubular wheel has a greater pumping effect, the power requirement for the tubular wheel is slightly higher.

Figure 9 is a line diagram of the heavy black liquor cycle. The salt cake mixing tank is shown to the upper right hand side of the cascade evaporator with a pipe line running from the bottom of the sale cake mixing tank into the primary heater, from the priheater into the black liquor pump, then through the secondary heater and then up and around to the furnace. A return line to the salt cake mixing tank is also included to provide a means for circulating liquor through the cycle even when the sprays are shut off. The addition of salt cake as a make-up chemical to the black liquor cycle must take place previous to the combustion of the black liquor in the furnace because the chemical that is required in the digester is sodium sulphide. The make-up chemical that is used is in the form of sodium sulphate which is "salt cake." That reduction must take place in the presence of carbon on the furnace hearth. The chemical reaction, of course, is:

$$Na_2SO_4 + 2C = Na_2S + 2CO_2$$

It is not practical to add salt cake to the black liquor before the cascade evaporator because it settles out in the cascade evaporator. For that reason, it is added to the cycle between the cascade evaporator and the furnace. *Figure 10* shows the arrangement of a salt cake mixing system. Located underneath the salt cake silo is the salt cake feeder which is a variable speed screw conveyor to vary the quantity of the salt cake fed to the black liquor as it flows through the salt cake mixing tank. From the salt cake conveyor the salt cake falls into a vibration screen which permits the fine particles to fall through into the same salt cake mixing tank. The rejected particles fall from the top of the screen through a spout and are collected and refed to the salt cake crusher.

Figure 11 shows the arrangement of the black liquor sprays on the rocker supports and connected to the heavy black liquor piping by the heavy flexible rubber hose. *Figure 12* is the assembly of the mechanical type breaker plate spray for the black liquor.

Recovery Furnace

The furnace operation can be considered to be divided into three different zones. There is no definite line of demarcation between the first zone, which is the drying zone and occurs approximately at the spray level, and the second zone, located just below, which is the secondary combustion zone, located just below, which is the secondary combustion zone where the initial combustion of volatile occurs. In this zone the burning of the CO from the fuel bed is also completed by the admission of the secondary air. Directly on the hearth is located the third zone in which the primary combustion and the smelting and reduction take place. Since a reducing atmosphere must be maintained in the fuel bed, the gas leaving the fuel bed is high in CO. The fuel bed is composed of the particles of the dry ash. The spray forms particles about one quarter inch in diameter which fall to the hearth and

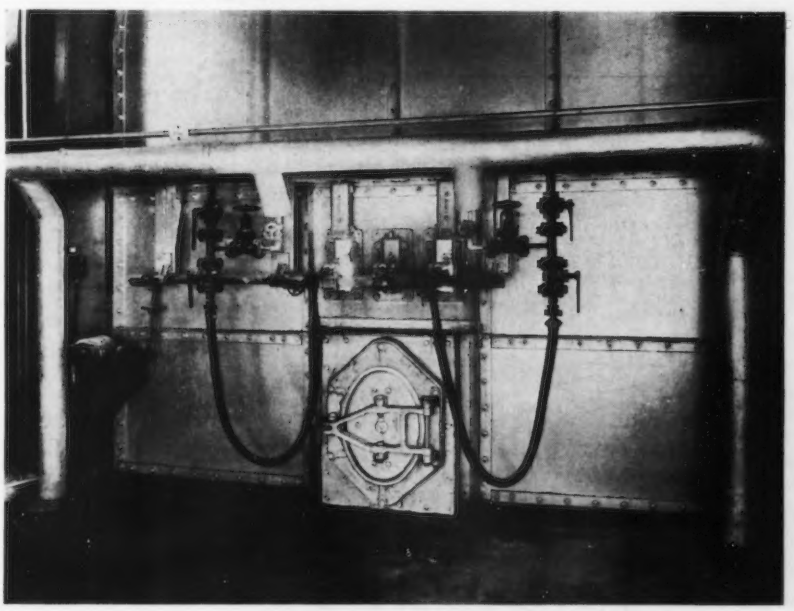
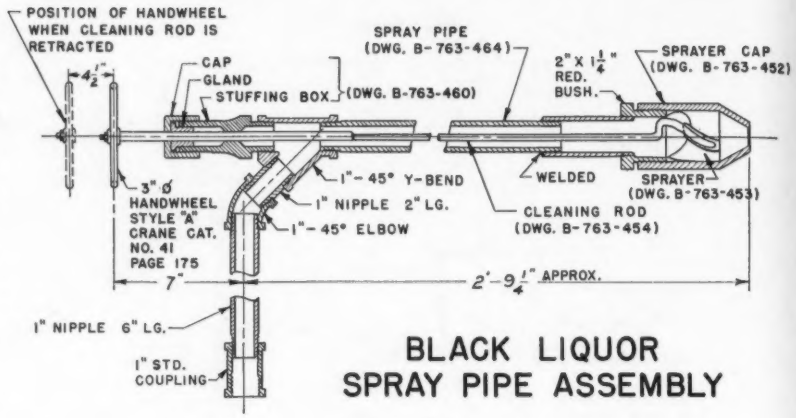


Figure 11

form a porous fuel bed. The air passing over the outer surface unites with the residual carbon in the fuel bed which produces CO which passes up higher where combustion is completed by admission of the secondary air. At the same time in the fuel bed the chemical is smelting and dropping down through the porous fuel bed, collecting on the hearth and running out the smelt spout. While the smelt passes down through the bed, the salt cake is reduced to sodium sulphide. *Figure 13* is a side view of the lower furnace arrangement.

The sprays oscillate from a horizontal plane down to approximately a 30 degree angle at a speed of six revolutions per minute. This oscillation distributes the dry fuel across the width of the furnace. The spray on the left hand side of the furnace throws the fuel over to the right hand side and, vice versa, the right hand spray throws it over to the left hand side. By means of the oscillation, the ash is evenly distributed across the width of the furnace hearth. The air requirements and gas quantities from combustion are as determined by the combustion characteristics curve mentioned previously.

Figures 14 and 15 are photographs of the lower and upper furnace tube walls. The recovery furnace is a completely water cooled furnace. The lower furnace tubes are three inches in diameter on five and one-eighth inch centers. Each side of the tube contains one inch square fins one-fourth inch thick. On the lower walls up to the level of the primary air ports, these square fins are also placed on the furnace side of the tubes. Chrome ore is packed around these fins when the unit is first constructed to protect the tubes in this area. The molten smelt will partly wear away this chrome, but a layer of chilled smelt will replace this chrome and act as a protector. This is more of a precautionary measure than a necessity for no wear occurs. Inspection of the lower furnace walls after several years operation, including those tubes surrounding the spout opening which are the most vulnerable, show no evidence of wear. A detail of the lower furnace will construction is shown in *Figure 16*. As previously mentioned, the fins and chrome placed on the furnace side of the tube exists only below the primary air port. Above this the furnace side of the tube is plain. *Figure 19B* shows a section through the upper furnace wall. The tubes are three inches in diameter on six inch centers and include a continuous fin one and seven-sixteenth inches wide on each side. The furnace metal walls, although also acting as protection for the refractories, are primarily heat absorption surfaces reducing the temperature of the flue gases. A recovery furnace must be designed so that the temperature of the gases entering the superheater area is reduced to approximately 1400 degrees Fahrenheit.



BLACK LIQUOR SPRAY PIPE ASSEMBLY

Figure 12

The importance of the refractory protection function of complete metal wall was demonstrated vividly in the first C. E. unit by the absence of the metal wall in the upper furnace. In this unit the upper side water wall tubes were three inches in diameter on 12 inch centers, and the upper front walls were three inches in diameter on six inch centers. Since the tubes were plain, without fins, the smelt that formed on the tubes could run completely around on the back side of the tube between the tube and refractory. This smelt pushed the tube away from the refractory. After a few months of operation, the accumulated chemical pushed the tube forward an excessive amount as shown on *Figure 16C*. With the finned tube construction of the all metal wall, the gap between fins is one-eighth of an inch. The smelt will chill on the face of the fin and not enter the gap a sufficient depth to form a hold on the tube and fin surface. This affords a self-cleaning wall for the chilled smelt will fall from the wall before a large mass is formed.

To prevent the tube movement

ARRANGEMENT OF SPRAY TYPE RECOVERY FURNACE

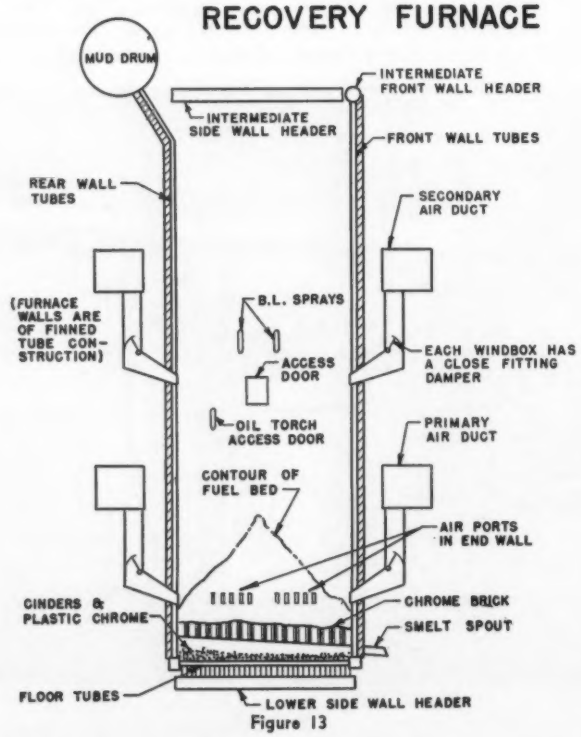


Figure 13

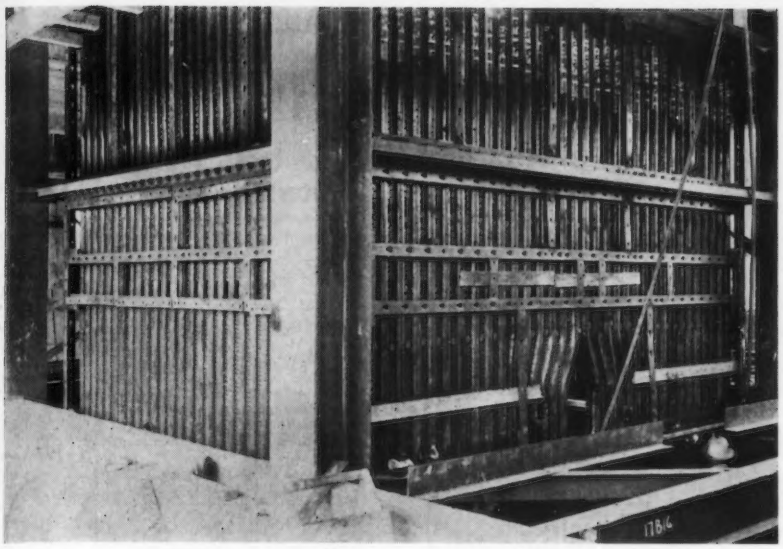


Figure 14

shown in *Figure 16C*, tube tie backs were installed as shown in *Figure 16*. This was merely a hooked bolt, the hooked end of which is fitted in a slot in a plate welded on the refractory side of the tube. The other end extended outward through the refractory and casing and the nut was turned up to give the necessary snugness to the casing, refractory and tube. The design of these tube tie backs has been improved to the shoe bolt design which can be seen on tubes in photograph of the upper furnace tubes on *Figure 15*.

Recovery Boiler

The waste heater boiler arrangement is shown in *Figure 1*. The gases pass upward from the furnace over the boiler screen tubes and superheater elements. After passing over the top of the metal baffle behind the superheater, the gases flow downward through the first boiler pass, reverse and move upward through the second pass. They then reverse and turn downward through the rear pass which is a third boiler pass as shown on this arrangement. In all recent designs, the boiler includes two passes and an integral economizer is located in the rear pass. The economizer is designed with tubes arranged vertically and extended between two headers located at approximately the same elevation as the drum centers. The feed water enters the lower economizer header and rises up through the economizer tubes. This arrangement gives a counterflow economizer with the gases entering at the top of the pass and travelling downward.

The ash is cleaned on the screen pass and in the superheater tubes, falls directly down onto the furnace hearth where it is smelted and runs out of the spout opening. The ash that is cleaned off the tubes in the second boiler pass behind the top of the first baffle and in the third boiler pass falls down into the hopper and is collected in the chemical ash recovery system which is shown on Figure 1. The boiler ash hoppers ("P") are shown at the top. Black liquor enters the bottom of the hopper and washes out the ash as it falls into the hopper. This solution flows by gravity into the chemical ash tank ("R"). Liquor from the multiple effect evaporator is used to collect this ash. This ash in solution is thereby returned to the mill liquor supply. It is a completely automatic system and there is no manual labor required for it except checking the hoppers once every hour to make sure that the ash is not crusting and is feeding downward with the liquor.

When the wet system for the handling of chemical ash was designed, water was used. At that time the use of black liquor was avoided for fear that it would build up in concentration and solidify. The next step was the feeding of the weak black liquor of approximately 15 percent dry solids. Now the system has progressed to using liquor at the concentration normally fed to the recovery unit. The disadvantages, of course, of using water or weak liquor to pick up the ash is that additional water entering the system has to be evaporated by the recovery unit and detracts from the heat available for producing steam.

Air and Flue Gas Equipment

The design of the forced draft fan for a recovery unit is not unusual. Air preheated to a temperature of 300 degrees Fahrenheit has proven to be a great advantage in the operation of a recovery furnace. The first C. E. spray type recovery unit constructed in 1937 included a conventional type flue gas air heater. The cleaning of the encrusted chemical on the tube surfaces proved to be a severe problem and appreciable quantities of steam were required for the soot blowers. To avoid these operational problems, a steam type air heater was incorporated in subsequent C. E. recovery units. The steam air heater is composed of twelve or sixteen steam heating coils of the design shown in *Figure 17*. The coils now being used are the American Blower Corporation's Type H heavy

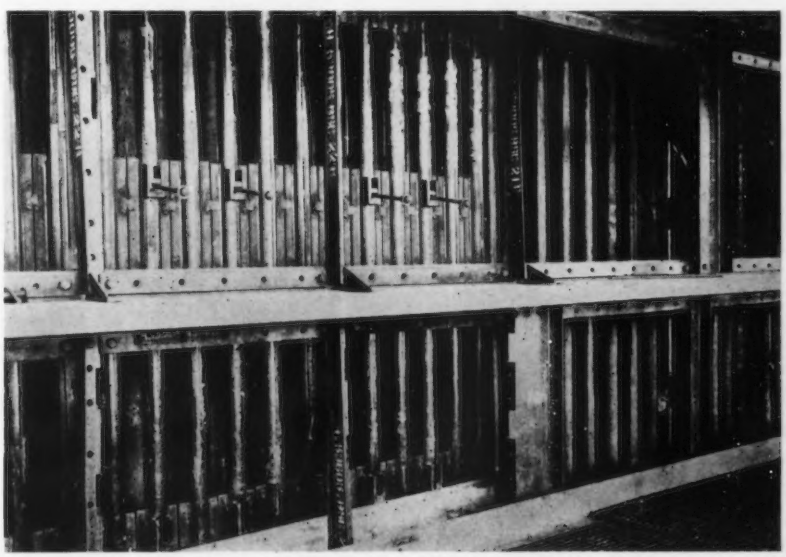


Figure 15

duty coil designed for a maximum pressure of 350 pounds per square inch gauge, temperature of 600 degrees Fahrenheit. Steam at approximately 150 pounds per square inch gauge or a combination of 150 and 50 pounds per square inch gauge is used to heat the air. This steam is obtained from the bleed steam from the power turbines which use the higher pressure steam produced by the recovery boiler. The steam coils are arranged in four rows in series, each row being three or four sections wide. This affords minimum air pressure drop and convenient arrangement of steam and condensate piping for the heater.

In addition to the operational advantage already mentioned, namely elimination of the cleaning problem, the steam air heater also has the operational advantage of producing maximum air temperature at the time most needed. These times are during start-up of the recovery unit and during interruptions in normal furnace operations. The flue gas air heater depends upon the flue gas temperature for the maximum air temperatures. At start-up and during interruptions, the required gas temperatures are not prevalent and the desired high air temperatures cannot be obtained with a gas air heater.

Heat-economywise, the steam air heater is an advantage because no heat is lost except radiation and additional steam at high pressure level is produced to generate extra electrical power. Steam at the turbine bleed pressure enters the heater and the heat of vaporization of this steam is transferred to the air entering the furnace. This heat is absorbed by the boiler to produce extra high pressure steam. This high pressure steam expands in the turbine down to the bleed pressure of the steam fed to the heater and in so doing, produces additional electrical energy. The condensate from the steam heater is returned to the feed water so this heat is also recovered.

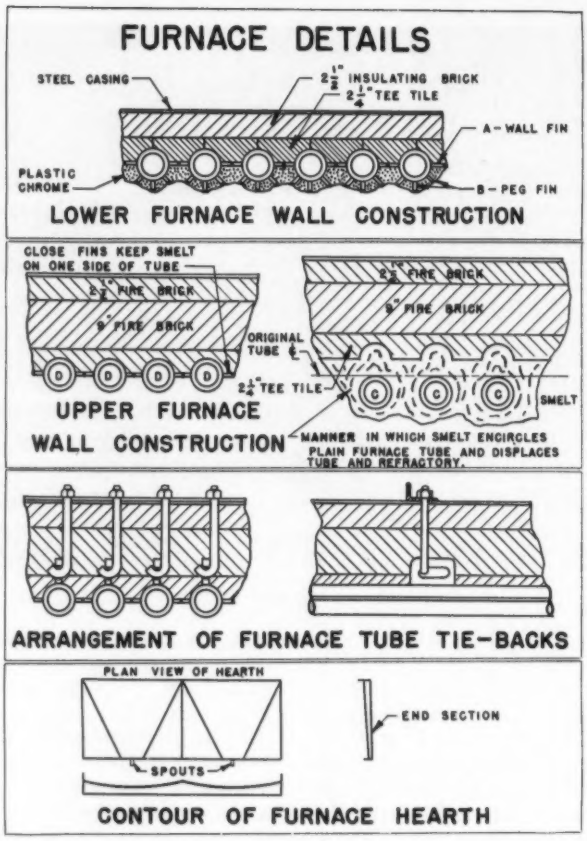


Figure 16

No operational cleaning is required for the steam air heater. Occasionally at a scheduled shut-down, the air side of the coil will require cleaning if dirty air enters the forced draft fan during operation. During operation, no steam is lost for cleaning the air heater. On the other hand with the flue gas air heater, the heat in steam used for cleaning is lost as well as the condensate from this steam.

Table I is a study made for a 250 ton chemical recovery unit showing the comparison between a steam air heater and a flue gas air heater. The study shows higher net heat recovery with the steam air heater and also shows the money savings resulting from the increase in electrical power generated.

The advantages of a steam air heater are as follows:

1. Clean surface at all times;
2. Uniform high air temperature; High temperature available for starting up and also for interruptions of furnace;
3. No heat loss (except radiation) in steam used for air heater;
4. No condensate loss;
5. Extra electrical power from increase in high pressure steam produced by unit.

We have had trouble with steam leaks in the heating coils, but these are not prevalent in the heavy duty steam coil now being used.

The disadvantages of a gas air heater are:

1. Cleaning necessary;
2. Variable air temperatures. Low air temperatures caused by dirty surfaces and by interruptions in operation;

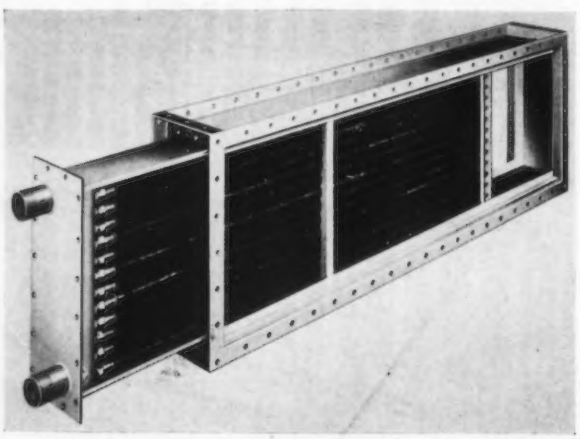


Figure 17—ABC Heavy Duty Steam Coil for Preheating Air

TABLE I

Comparative Study-Steam Air Heater vs. Gas Air Heater
250 Ton Recovery Unit

Equipment Variation	Steam Air Heater I Steam Air Heater and Economizer	Gas Air Heater II Gas Air Heater
#Dry Solids/Hour	31250	31250
% Dry Solids in Black Liquor	50	50
Heating Value D.S. BTU/Lb.	6500	6500
STEAM AND CONDENSATE RATES		
Steam Production	109500	102300
Steam Pressure and Temperature	575 PSIG—700 Deg. F.	575 PSIG—700 Deg. F.
Feedwater Temperature	220	220
Air Heater Condensate Rate Lbs./Hr.	9600	.....
Air Heater Steam Pressure	125 PSIG Sat.	.....
Steam for Cleaning Heater Lbs./Hr. (Ave.)	0	1000
HEAT COMPARISON		
Heat in Steam from Recovery Unit (1350 BTU/Lb. Steam) Million BTU/Hr.	148.2	138.5
Heat in Steam to Air Heater	11.45	.....
Heat in Steam to Clean Air Heater		1.35
Net Heat in Steam from Recovery Unit	136.75	137.15
Heat in Condensate Returned to Cycle	3.12	.....
Net Heat from Recovery Unit to Steam	139.87	137.15
POWER COMPARISON		
Increase in Steam Flow to Turbine Resulting From Steam Air Heater (Lbs./Hr.)	7200	
Assumed Turbine Water Rate Lbs./Kwh.	36.0	
Electrical Energy Produced Kwh.	200	
Dollar Return per Hour at 5 Mills/Kwh.	$1.00	
Savings per Year (330 days operation)	$7920	

3. Heat loss in steam used for cleaning surfaces;
4. Condensate lost from steam to air heater soot blowers.

The selection or type of induced draft fan is highly critical because of the chemical entrained in the flue gases. The impact of the ash particles on the rotating fan blades causes a heavy build-up of the ash on the blades. A heavy build-up on the fan rotor can cause unbalance and vibrations. The American Blower Co.'s Sirocco type fan has been selected for this severe service. The rotor of this fan is shown in *Figure 18*. The fan blade is a comparatively deep cup of short radial depth. This short depth radial blade curtails vibrations because it limits the possible difference in the radius of the particles deposited on the various blades in the rotor. The induced draft fan is selected for a maximum speed of 900 revolutions per minute for units up to 300 tons capacity and 720 revolutions per minute for the larger units.

Induced draft fan control is of importance in recovery unit operation. Normally a hydraulic coupling driven by a constant speed motor drives the fan. Variable speed turbines have been used in a few installations. A variable speed drive on the fan gives the best operating condition because it affords the minimum speed required for the fan. Induced draft fans are selected with a 30 percent safety factor in gas volume and about 100 percent safety factor in static pressure. The cleaning of the recovery unit is done almost completely by automatic mechanical equipment and the failure of any one of the cleaning elements could result in increased draft loss for that particular location. The induced draft fans are selected with a large safety factor in static pressure to insure continuity in operation even at times of increased draft loss while soot clean equipment is being repaired. Because of this large static pressure safety factor, the fan, with variable drive, rotates at an appreciably reduced speed during normal operation. The horsepower consumption of a fan rotating at this reduced speed is much less than that required for a fan operating at full speed with volume and pressure head controlled by an outlet damper. This is shown by a study given later.

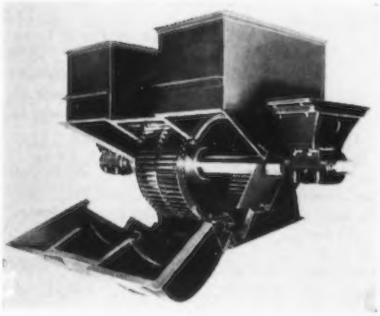


Figure 18—ABC Sirocco Type Induced Draft Fan

Another factor to be considered for fan operation is that the cleanliness of the boiler surfaces will vary during the cleaning cycle of the boiler so that even for the same black liquor burning rate the static pressure load on the fan will vary over a six or eight hour period of operation. To meet these varying conditions for fan performance, the hydraulic coupling drive is applied to the induced draft fan for it affords the exact fan speed required for the operation. The hydraulic coupling has a slippage loss for the lower speeds but the saving in horsepower mentioned previously more than off-sets the additional motor horsepower over the fan horsepower caused by the coupling slippage. This is shown by the study made in *Table II* for a 350 ton Recovery Unit.

A sectional view of the American Blower hydraulic coupling is shown in *Figure 19*. The impeller, with the inner and outer casings, is driven through the impeller shaft by the constant speed motor. The runner is sup-

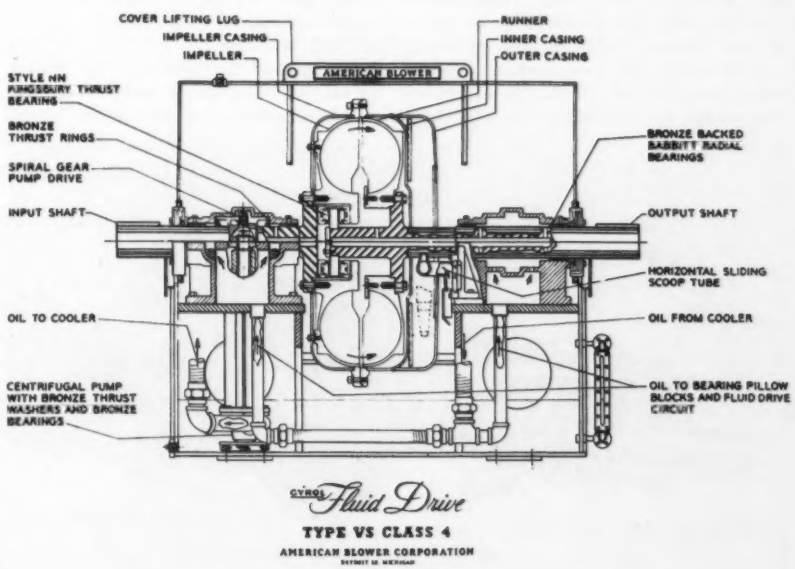


Figure 19

ported by the driven shaft and positioned inside of the inner casing. Both the impeller and the runner contain radial vanes or blades. Power is transmitted from the impeller to the runner by means of the oil contained within the working circuit. The working circuit is composed of the impeller, runner and the inner casing. The speed of the fan, driven by the coupling, varies with the quantity of oil contained in the working circuit of the fluid drive. A portion of oil in the working circuit leaks out from the inner casing through calibrated nozzles into the space between the inner and outer casings. A fixed scoop tube located between these casings removes this oil and circulates it continuously through the oil cooler. It is returned to the working circuit through the manifold. The base of the coupling contains an oil reservoir. A pump takes oil from this reservoir and pumps it into the working circuit or vice versa, to give the desired speed of the fan. This reversing oil pump is electrically driven and controlled by the furnace draft regulator.

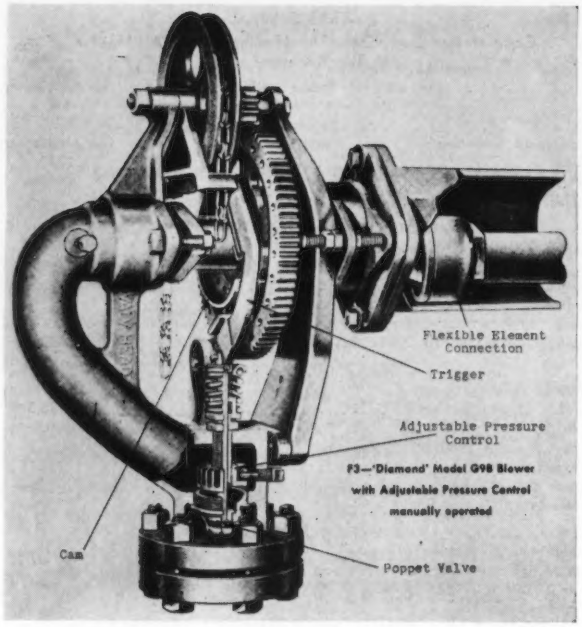


Figure 20

TABLE II
Comparison of Power Consumption for Induced Draft Fan
350 Ton Recovery Unit
Induced Draft Fan Control
Outlet Damper vs. Hydraulic Coupling
#1 D.I. 2/3 D.W. Sirocco A.B.C. Fan—(Dirty Blade Conditions)

Per Cent Rating	75 Per Cent		100 Per Cent		Test Block	
Method of Control	Damper	Hydlc. Coup.	Damper	Hydlc. Coup.	Damper	Hydlc. Coup.
Gas Volume		83,500		119,200		165,000
Gas Temperature		300		300		300
Fan Inlet Draft		4 Inches		6 Inches		10 Inches
Fan Speed	680	420	680	517	680	680
Fan B.H.P.	243	88.5	335	192	457	457
Hydlc. Coup. B.H.P. .		150		264		480
Motor Load H.P.	243	150	335	264	457	480

Soot Blowing Equipment

The problem of cleaning ash from the gas swept surfaces of the recovery boiler has always been foremost in recovery unit operation. Consequently, soot blowing equipment and its application to the recovery unit has always been important. Steam from the boiler outlet header has been the main source of supply for the soot cleaning medium. Since 1944, several units have been installed using compressed air as the cleaning medium, the air being supplied by air compressors at a pressure of 250 to 350 pounds, depending upon the width of the boiler and length of soot blower elements.

In all cases, the soot blowing equipment has included a rotating element, the nozzles being arranged to blow between the rows of tubes cleaning the ash from the surfaces of the tubes. In the first spray type recovery units, all these rotating elements were located in fixed positions in the boiler passes and supported horizontally from hangers on the boiler tubes. This fixed location rotating type unit is still used in the boiler passes behind the first boiler baffle. This type element located before the first baffle would not withstand the washing effect of the high temperature of the chemical laden gases that prevail in this section of the boiler. A retractable type soot blower element was therefore applied. This retractable element is only in the hot gases for the period of time required to travel in and out for the designed length of travel. In narrow boilers with single sided soot blower heads, the length of travel is equal to the width of the boiler. On larger units, two soot blowers are included for each location so the travel is one half of the width. In some recovery rooms, due to location of adjacent boilers and equipment, aisle space on the sides of the unit are not equal, and in such cases the retractable blower on one side will have a longer travel than on the other.

Steam was used originally in the first, fixed position soot blowers in recovery units. This type head is shown in *Figure 20.* This is a manually op-

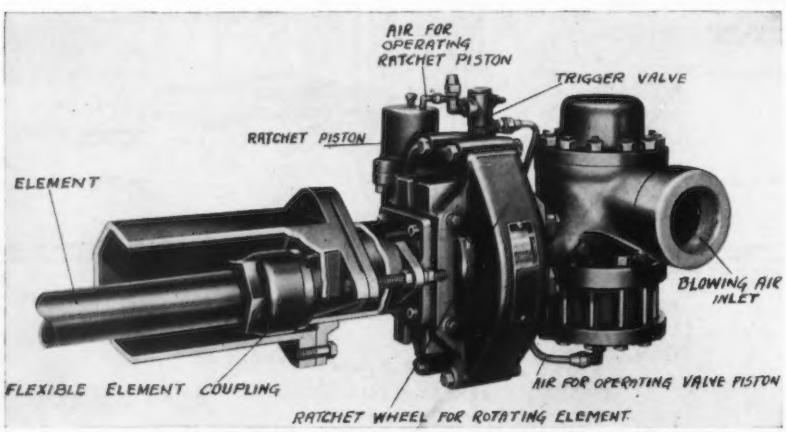


Figure 21—Diamond Model A2e Air Puff Soot Blower Head

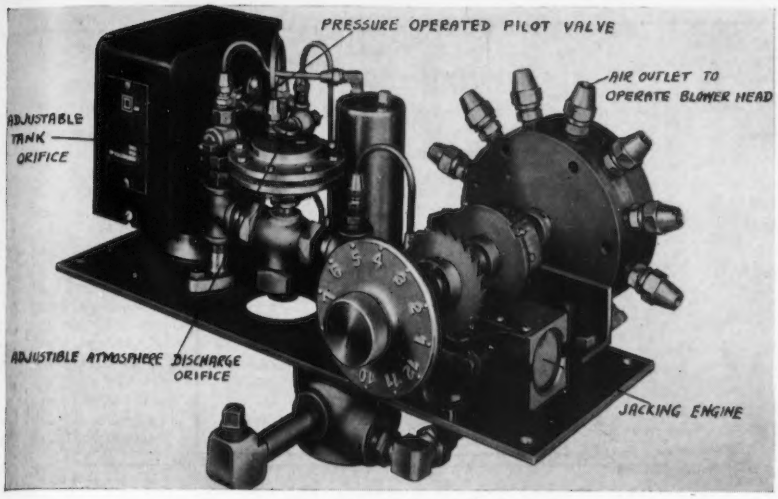


Figure 22—Diamond Ame 14 Master Controller

erated head, the head being connected to the rotating element by the flexible connection shown. The movement of the cam on the geared driving wheel opens the poppet valve to admit steam to the element. The steam passes through the nozzles located between each row of boiler tubes. The cam is of sufficient length and so located on the drive wheel to have the steam blow through the proper cleaning arc and also permit the poppet valve to close at the completion of this arc of travel.

In 1944 the first air puff soot blowing system was applied to the chemical recovery unit to replace the steam blowing fixed position manually operated system. This was at the S. D. Warren Co. mill at Cumberland Mills, Maine. This system consists of the necessary elements and fixed location heads which blow compressed air and are also operated through the automatic sequential controller. *Figure 21* shows the Diamond Power Specialty Corp.'s air puff head. The following is their description of its operation.

"The Model A2E Automatic Air Puff Head delivers a series of compressed air puffs to the soot blower element while the element is intermittently revolved through a predetermined blowing arc. The beginning of each step in the element's rotation is simultaneous with the opening of the main valve that delivers the blowing air directly from the receiver. The end of each step of the element's rotation is also simultaneous with the closing of the main air valve (which ends the puff.)

"Element rotation is accomplished by means of an air-operated ratchet piston and pawl acting upon a ratchet gear. The main air valve is actuated by an air-operated piston. Both ratchet piston and main valve piston are operated by control air impulses delivered by the Diamond Master Controller. When the blowing arc is less than 360 degrees, a cam and a trigger valve are interposed in the control circuit to the main air valve so that this valve will open only during the blowing arc.

"Model A2E heads are especially designed for using air and have low pressure drop at high flow rates."

Figure 22 shows the Diamond Power Specialty Corp.'s Master Controller for air puff operation and the following description is quoted from Diamond Power Specialty Corp.'s catalogue.

"When a valve is opened, the Master Controller activates the first blower head in the sequence. During the blowing cycle it controls the duration of the air puffs and the intervals between puffs; it regulates the impulses of air which rotate the blowing element through a small arc during each puff and opens the main air valve in the blower head. After completion of the blowing cycle for the first blower of the sequence, the Master Controller automatically changes the blowing of the next head . . . and so on throughout the sequence."

In comparison with steam as a soot blowing medium, compressed air has the advantages of higher density, lower temperature, aind, comparatively speaking, no moisture. The result of the mass puff of cool dry air is cleaner surfaces of the boiler tube which is evidenced by a lower unit gas temperature from the boiler and lower draft loss. Since the first application of the air puff system, the majority of recovery units installed have included the air puff. The initial installation cost of the air puff system is greater usually by the amount of the cost of the high pressure air compressor and receiver but savings in operation has justified the air puff system. Actual application to any mill can only be determined after an evaluation of the air and steam costs required for the soot blowers. The automatic sequential air puff system for the cleaning of the boiler surfaces gave the advantage of automatic blowing cycle which eliminated the deficiencies in cleaning caused by the human element, these deficiencies being non-uniform blowing time of each head each time blown, and also possibly of forgetting one head in the period of blowing. The automatic blowing also helped to reduce the work of the boiler cleaning personnel. In some cases where steam is the more economical cleaning medium, the advantages of the automatic sequential blowing is obtained by using an air or electric motor to drive the steam blowing fixed location head.

The retractable type steam blowing air driven soot blower applied to the screen pass and superheater pass of the recovery boiler is shown in *Figure 23*. The outer end of the rack can be seen as well as the pinion gear. The air for driving the head can be manually or remote automatically controlled. The air motor drives the gear and projects the blower into the boiler at the same time rotating the blower.

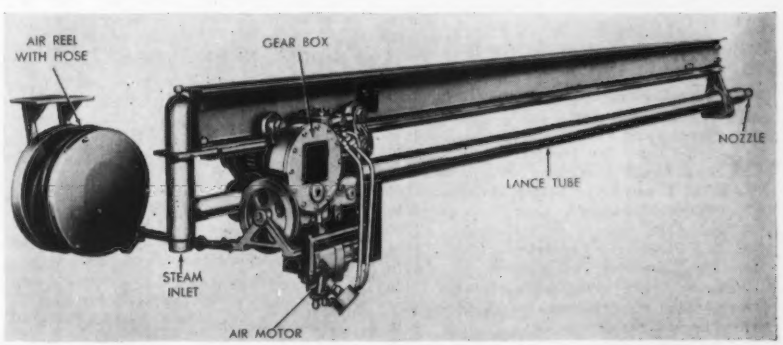


Figure 23—D3—"Diamond" Model IK Long Travel Retracting Blower, Air Motor Operated, Independent Hand Valve Steam Control

When the blower advances to its initial blowing position, a cam opens the steam valve and admits steam to the blower. The blower is automatically reversed when it reaches its maximum travel and the steam is automatically cut off when it again reaches its retracted position. In most mills the soot blower installations have included an automatic control panel to give complete automatic sequential operation of all the retractable and the stationary heads.

Green Liquor System

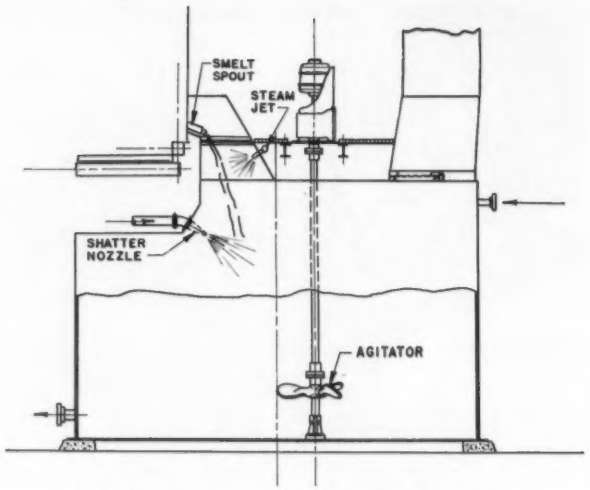
The molten ash flows over the hearth of the recovery furnace, out through the smelt spout, and falls into the dissolving tank where it forms the green liquor. The hearth of the recovery furnace is shown in *Figure 13.* This design shows the refractory hearth supported free of the circulating tubes. The hearth is constructed on a steel plate which lays on channel irons extended between the front and the rear wall headers. The cinder concrete fill is shoped to form the contour for drainage toward the spout openings as shown at the bottom of *Figure 16E.* On units below 14 feet in width, one spout is used; on larger units, two spouts. Chrome brick is layed on top of the concrete fill. Chrome ore withstands the washing action of the molten smelt better than any other known refractory.

The smelt spout is a water-cooled trough constructed with internal baffling to afford maximum water velocity under the hottest plate section and thereby attaining the maximum heat transfer rates and cooling effect.

The collection of smelt in the dissolving tank is a ticklish problem because of the inherent explosive characteristic of the molten smelt when submerged in the comparatively cool liquid. To avoid serious explosion, it is necessary to disperse the smelt stream before it enters the liquor. This is accomplished by means of a spray nozzle located directly under the smelt spout. Liquor for this spray is circulated by the green liquor circulating pump which draws liquor from the bottom of the dissolving tank and circulates it through the spray nozzle. The smelt dissolving tank and spray nozzle is shown in *Figure 24.* The circulating pumps are located on the basement floor to the rear of the main dissolving tank.

A steam jet blowing directly onto the smelt leaving the spout has also proven to be an excellent means for dispersing the smelt and avoiding explosions in the tank.

An agitator is installed in the main dissolving tank to insure proper mixing of the smelt and uniform density in the green liquor pumped from the main dissolving tank to the causticizing department.



SMELT DISSOLVING TANK
Figure 24

Controls and Instruments

The recovery unit is operated at uniform ratings acting as a base load boiler so no elaborate combustion controls are necessary. The boiler instruments consist of the conventional flow, temperature, and draft meters. The steam flow meter indicates, records, and integrates steam flow. The same meter case will also include a steam temperature pen, and, usually, a boiler outlet draft recorder.

The air flow meter records air flow by measuring the pressure drop across the steam air heater. This meter also records the gas temperature from the economizer, and the gas temperature from the cascade evaporator. A multipoint indicating meter indicates the draft at each pass in the boiler as well as cascade evaporator outlet draft. This same meter includes indicators for the primary and secondary air pressure as well as a temperature indicator for the air temperature leaving the heater. The steam air heater gives a constant air temperature so a recording instrument is not needed.

The furnace draft is controlled by a Leeds & Northrup furnace draft controller. The draft connection to this is located in the upper furnace and is set to give a negative pressure of approximately 0.2 inch. The draft impulses are transferred to an electrical relay in the Leeds & Northrup instrument. The electrical impulses operate the control pump motor in the hydraulic coupling which drives the induced draft fan, thereby giving the necessary fan speed to control the furnace draft.

The forced draft is manually controlled by a push button which operates the forced draft fan outlet damper.

The black liquor flow to the recov-

TABLE III

Recovery Unit Capacities		100 Ton	200 Ton	300 Ton	350 Ton
Application	Recommended Speed	No. HP	No. HP	No. HP	No. HP
1. Evaporator Gear Reducer	1170	1–30	2–40	2–40	2–50
2. Induced Draft Fan	860	1–150	1–300	1–450	1–500
3. Forced Draft Fan	1170	1–75	1–125	1–150	1–200
4. Forced Draft Fan Damper	1750	1–⅛	1–⅛	1–⅛	1–⅛
5. Black Liquor Pump	600/1200	2–30	2–40	2–40	2–50
6. Black Liquor Spray Nozzles	1750	2–¼	2–¼	2–¼	2–¼
7. Scraper Mechanism	1750	1–½	1–½	1–1	1–1
8. Salt Cake Agitator	1750	1–5	1–5	1–5	1–5
9. Salt Cake Screw Conveyor	1170	1–2	1–3	1–3	1–3
10. Main Dissolving Tank Agitator	1170	1–15	1–20	1–25	1–25
11. Green Liquor Recirculating Pump	1170	2–15	2–20	2–20	2–25
12. Chemical Ash Agitator	1170	1–5	1–5	1–5	1–5
13. Chemical Ash Pumps	1170	1–7½	1–7½	1–10	1–15
14. Air Compressor	1170	1–75	2–75	2–125	2–125
15. I.D. Fan Hydrlc. Coupl. Control	1750	1–¼	1–1	1–1	1–2

TABLE IV

Application	Name Plate Rating HP	Volts	Amps.	Actual Amperage
1. Dissolving Tank Agitator	20	440	25.6	14
2. Dissolving Tank Circulator	40	440	51.5	North—47 South—Down
3. Dissolving Tank Transfer	40	440	51.5	30
4. Black Liquor Feed Pump	50	440	64.0	Number Two—34.0
5. Black Liquor Flow Box Scraper	1	440	1.5	1
6. Salt Cake Drag to Crusher	20	440	20.6	5
7. Salt Cake Crusher	30	440	38.9	15
8. Salt Cake Screw to Elevator	2	440	2.8	1
9. Salt Cake Elevator	5	440	6.5	2.5
10. Salt Cake Drag Number One	5	440	6.5	5
11. Salt Cake Drag Number Two	5	440	6.5	2.5
12. Salt Cake Screw to Mix Tank	3	440	4.7	1
13. Salt Cake Mix Tank Agitator	10	440	13.7	6
14. Ash Tank Circulating Pump	15	440	18.8	16
15. Ash Tank Agitator	5	440	7.45	Number One—North 2.5 Number Two—South 2.5
16. Cascade Evaporator	40	440	51.0	Number One—North 22.0 Number Two—South 22.5
17. Forced Draft Fan	150	2200	37.0	32
18. Induced Draft Fan	400	2300	91.0	74

ery unit can be controlled in any of three ways:

1. By the multipoint rheostat included with the grid resistors and variable speed motor. Some mills have installed scoop tube type hydraulic couplings for affording variable speed operation of the black liquor pumps.
2. By the valves located at each black liquor spray. This usually affords only minor adjustment in flow through the spray.
3. By the valve in the circulating header return line which recirculates the excess liquor back to the salt cake mixing tank.

The black liquor flow to the cascade is controlled by maintaining a constant level in the cascade evaporator. This is accomplished by means of a vapor filled thermometer bulb located above the wier in the flow box at the discharge from the cascade evaporator. This vapor filled bulb is connected by means of a vapor filled capillary tube to an air operated controller which actuates the valve located in the black liquor line to the cascade.

The black liquor temperatures leaving the primary and secondary heaters are controlled by the same type controllers which control the amount of steam fed directly into the liquor in the heaters.

The instrument panel will also include the following instruments:

- Feedwater pressure gauge
- Service water pressure gauge
- Steam pressure gauge
- Service steam pressure gauge
- Weak black liquor gauge
- Strong black liquor gauge
- Heavy black liquor gauge
- Ammeters for the cascade evaporator motors
- A water level recorder or indicator or both.

These instruments are the usual ones included. Some include more elaborate panel boards including feedwater meters, recording water meters and etc.

Heat Balance for Chemical Recovery Unit

The detailed description and formulae pertaining to the heat balance is covered in Chapter 5 of the 1950 edition of "*Manufacture of Pulp and Paper.*" The normal conditions for a heat balance study are as follows:

Quantity Dry Solids	One Pound
Moisture content in black liquor	50 Per Cent
Heating value per pound dry solids	6500 BTU (high)
Salt Cake added per pound dry solids	0.1 Pound
Temperature air to unit	80 Degrees Fahrenheit
Temperature Black Liquor to Unit	200 Degrees Fahrenheit
Dry solids analysis	C = 33 per cent, H = 3.5 per cent, O_2N_2 = 15.0, S = 3.0 per cent, Ash = 45.5 per cent.
Temperature Basis	32 Degrees Fahrenheit

Under these conditions the heat distribution for the various components are as follows:

Heat Input	BTU
Heating value of Black Liquor	6500
Sensible Heat in Black Liquor	246
Heat in Steam to Air Heater	382
Heat in Steam to Liquor Heater	55
Heat in Air to Unit	157
Total Heat Input	7340
Heat Distribution	**BTU**
Heat in Water Vapor in Flue Gas	1720
Heat in Dry Gases	406
Heat for Reduction of Salt Cake	600
Sensible Heat in Smelt and Fusion	257
Heat in Condensate from Air Heater	86
Radiation and Unaccounted For	367
Heat Available for Steam	3904
Total Heat Distributed	7340

The steam flow from the recovery unit will be equal to the heat available for steam divided by the heat required to generate one pound of steam. This heat to each pound of steam depends upon the operating conditions for any particular installation. The conditions depend upon the three following items:

- Pressure Steam Leaving Recovery Unit
- Temperature Steam Leaving Recovery Unit
- Temperature Feedwater to Recovery Unit

The chemical recovery unit in the pulp and paper mill is a necessary and highly important part of the mill steam generating plant. The design and operation conditions for a recovery unit will depend upon the steam and power balance for the mill. Specified design conditions, that is, steam pressure and temperature, have increased along with the general upward trend in those specified for industrial boilers. The maximum conditions designed for to date is 900 pounds per square inch, gauge, pressure and 825 degrees Fahrenheit temperature.

TABLE V
Building Dimensions for Various Recovery Units

Recovery Unit Capacity	Approximate Dimensions Width	Depth	Height
100	37	56	90
150	42	72	95
200	50	77	95
250	56	77	95
300	60	80	100
350	60	82	102

Power Requirements

The quantity, horsepower rating, and speed of the motors required for various size recovery units is approximately as given in *Table III.*

Practical experience has proven the wisdom in conservative selection of electrical motors. *Table IV* shows the comparison of full load amperage and actual operating amperage consumed by the motors installed on a 275 ton chemical recovery unit. (All motors three phase, 60 cycle.)

Building Requirements

The chemical recovery unit is considered as the heart of the recovery process in the pulp mill. The concentrated black liquor is received from the evaporator room. The chemical recovery unit converts the latent heat energy in the black liquor to high pressure steam which is used to generate a larger percentage of the power to run the pulp mill and the exhaust from the generators provides the necessary process steam. At the same time, the recovery unit is pumping for reuse of the necessary chemicals for carrying on the pulping operations. The size of the recovery building is indicative to the importance of the recovery unit.

Table V gives the approximate dimensions of the buildings figured for various size recovery units.

Peroxides

Dr. J. S. Reichert

Manager, Peroxygen Products Development, Electro-chemicals Department, E. I. du Pont de Nemours & Co., Inc., Niagara Falls, N. Y.

Graduate, Miami University, Oxford, Ohio; M.S. from the University of Minnesota, Minneapolis, Minn.; Ph.D. from the University of Notre Dame, South Bend, Ind.

Lieutenant in the Chemical Warfare Service; supervisor of research on the production of war gases and on methods of protection against war gases.

Instructor in Chemistry, University of Minnesota; Professor of Chemistry and Assistant Dean, College of Science, University of Notre Dame; Researches on Acetylene Chemistry.

Supervisor of Production, Edible Products Department, the Procter & Gamble Co., Ivorydale, Ohio; Researches on the manufacture, distribution and uses of peroxygen compounds, Electrochemicals Department, E. I. du Pont de Nemours & Co., Niagara Falls, N. Y.; 32 publications and 128 patents on acetylene reactions and peroxide chemistry and technology.

Member Technical Assn. of the Pulp & Paper Industry; member of Pulp Purification and Non-Fibrous Raw Materials Committees; Chairman, Empire State Section, American Chemical Society.

PART I—MANUFACTURE, PROPERTIES AND USES

Introduction

It is indeed a privilege and a pleasure to meet with you here this morning. The University of Maine became renowned as a site of learning and culture while gaining popular acclaim from the rousing theme of your "Stein Song." Today your school is widely recognized as a center for training and research in the sciences and in engineering and is receiving special recognition for its competent staff and its excellent facilities in pulp paper technology. May I extend my sincerest congratulations to you Maine students in chemistry and chemical engineering, and to you Maine students who are following the curriculum in pulp and paper technology, upon the favorable environment which you have selected as a training ground for your chosen profession.

At the request of your faculty, I am here for two of your class periods this morning, for a review of a recent development in pulp and paper technology—the applications of peroxides in pulp bleaching processes. During the first period we will discuss the peroxides—their manufacture, properties and uses. The second period will be devoted to peroxide applications in pulp bleaching.

Historical

Sodium peroxide was first prepared in 1811 by Gay-Lussac by burning sodium metal in an atmosphere of oxygen. Hydrogen peroxide appropriately designated as "oxygenated water" by its discoverer Thenard, was first prepared in 1808 from barium peroxide and an acid. Sodium perborate, a hydrated addition product of hydrogen peroxide and sodium metaborate, was first prepared by Tanatar in 1898. Barium peroxide, the forerunner of hydrogen peroxide, was first prepared by Von Humboldt in 1799 by the oxidation of barium monoxide. Zinc peroxide was first prepared in 1818 from hydrogen peroxide and a slurry of zinc hydrozide by Thenard who earlier had discovered hydrogen peroxide. Calcium peroxide was first made in 1878 by Struwe by heating limestone in an atmosphere of oxygen. Many other peroxides have been prepared by the oxidation of a variety of inorganic and organic substances.

Preparation of Peroxides by the Oxidation of Inorganic and Organic Substances

It is of scientific interest that many inorganic as well as organic substances are so readily oxidizable to peroxides. Of the many inorganic peroxides obtainable by oxidation of the corresponding metal, only sodium peroxide is of major commercial importance. Among the numerous organic peroxides which have been prepared by direct oxidation, few have developed into commercial significance. Peroxide formation in organic oxidations constitutes a potential hazard since most organic peroxides are violently explosive; for example, ether explosions are generally attributed to the formation of a peroxide.

Synthesis of Hydrogen Peroxide from the Elements

A tremendous amount of investigational work has been done in the effort to develop a commercial process for the production of hydrogen peroxide by direct synthesis from the elements hydrogen and oxygen, so far without success. The following facts have been established:—(1) When hydrogen and oxygen react, the primary product is hydrogen peroxide, which rapidly decomposes into water and oxygen; (2) Rapid cooling of the reaction products retards the decomposition of hydrogen peroxide and so increases the yields, and (3) Yields of hydrogen peroxide are increased by activation of the reactants. The data on thermal activation show that hydrogen peroxide formation is favored by higher temperatures. Ionization of hydrogen and oxygen by silent electric discharge constitutes a basis for electrical activation. Irradiation with ultraviolet light, mercury vapor and corona discharge are also known to promote the reaction.

Production of Peroxides

In view of the importance of hydrogen peroxide and sodium peroxide in the pulp and paper industry, and considering today's time limitations, the subsequent discussions will be limited to these two peroxides.

Sodium Peroxide is produced in a two-stage oxidation of sodium metal, first with air to sodium monoxide and then with oxygen to the peroxide. Production of sodium peroxide by this route was started about the beginning of the present century.

Hydrogen Peroxide—Most of the world's supply of hydrogen peroxide is now being produced by four processes —

one chemical and three electrolytic. In the oldest process, the chemical process, the barium carbonate is converted to barium oxide by heating in the presence of carbon as a reducing agent. The barium oxide is oxidized to barium peroxide by heating in an atmosphere of oxygen. Finally, the barium peroxide is reacted with phosphoric and sulfuric acids to yield hydrogen peroxide and a valuable by-product, barium sulfate or blanc fixe. The chemical reactions involved in this process are essentially the following:

(1) $BaCO_3 + C \longrightarrow BaO + 2CO$
(2) $BaO + \frac{1}{2}\ O_2 \longrightarrow BaO_2$
(3) $BaO_2 + H_3PO_4 \longrightarrow H_2O_2 + BaHPO_4$
(4) $BaHPO_4 + H_2SO_4 \longrightarrow H_3PO_4 + BaSO_4$

$BaCO_3 + C + \frac{1}{2}\ O_2 + H_2SO_4 \rightarrow H_2O_2 + 2CO + BaSO_4$

In one electrolytic process sulfuric acid is oxidized to persulfuric acid in the anode compartment of the cell. The persulfuric acid is hydrolyzed to hydrogen peroxide and sulfuric acid; the hydrogen peroxide is separated by distillation. The recovered sulfuric acid is returned to the cells. The vaporized hydrogen peroxide is recovered by fractional condensation. The reactions involved in this process are essentially as follows:

(1) $2H_2SO_4 \longrightarrow H_2S_2O_8 + H_2$
(2) $H_2S_2O_8 + 2H_2O \longrightarrow H_2O_2 + 2H_2SO_4$

$2H_2O \longrightarrow H_2 + H_2O_2$

In the second electrolytic process the electrolyte, ammonium bisulfate, is oxidized to ammonium persulfate, which is converted to potassium persulfate by reaction with potassium bisulfate. The regenerated ammonium bisulfate is returned to the cells. Hydrogen peroxide is liberated from the potassium persulfate by steam distillation, fractionally condensed and subsequently fractionated to higher strengths when so desired. The regenerated potassium bisulfate is reused in the process. The reactions involved in this process are essentially as follows:

(1) $2NH_4HSO_4 \longrightarrow (NH_4)_2S_2O_8 + H_2$
(2) $(NH_4)_2S_2O_8 + 2KHSO_4 \longrightarrow 2NH_4HSO_4 + K_2S_2O_8$
(3) $K_2S_2O_8 + 2H_2O \longrightarrow 2KHSO_4 + H_2O_2$

$2H_2O \longrightarrow H_2 + H_2O_2$

In the third electrolytic process, as in the second, the electrolyte is ammonium bisulfate, but in this process the conversion of ammonium persulfate to potassium persulfate is omitted and the hydrogen peroxide is generated directly by hydrolysis of the ammonium persulfate in the cell liquors. The reactions involved in this process are essentially the following:

(1) $2NH_4HSO_4 \longrightarrow (NH_4)_2S_2O_8 + H_2$
(2) $(NH_4)_2S_2O_8 + 2H_2O \longrightarrow 2NH_4HSO_4 + H_2O_2$

$2H_2O \longrightarrow H_2 + H_2O_2$

Economical operation of the chemical process for the production of hydrogen peroxide requires an adequate outlet for a chemically equivalent tonnage of blanc fixe. The electrolytic processes require substantial blocks of electric power. Consequently, processes based on the synthesis of hydrogen peroxide from the elements, hydrogen and oxygen, have received attention, particularly in Germany, where high strength hydrogen peroxide was promoted during World War II as a source of power for the propulsion of submarines, torpedoes and air missiles. Processes based on the direct union of hydrogen and oxygen did not go beyond the laboratory stage. A process based on silent electric discharge and also indirect methods based on alternate oxidation and reduction of organic intermediates showed some promise.

Properties of Sodium Peroxide

"Solozone," duPont's sodium peroxide, is a pale yellow solid with a bulk density of 95 pounds per cubic foot. It is stable at ordinary temperatures when kept dry in closed containers and is readily soluble in water and in dilute acids. It is a strong alkali and an active oxidizing agent. In alkali value one pound of sodium peroxide is equivalent to slightly over a pound of caustic soda. It contains approximately 20 percent active oxygen.

Sodium peroxide readily absorbs moisture and carbon dioxide from the air, liberating oxygen and forming sodium carbonate and caustic soda. This material should therefore be kept in tightly closed containers. Undissolved sodium peroxide should not be allowed to come into contact with oxidizable organic materials except under carefully controlled conditions or spontaneous combustion may occur. Oxidation reactions and bleaching processes can be carried out safely and satisfactorily with aqueous solutions of sodium peroxide.

Sodium peroxide is especially useful for applications in which alkaline peroxide solutions are required. When solutions of sodium peroxide are neutralized with an acid, an equivalent amount of hydrogen peroxide is produced, along with the corresponding sodium salt.

Properties of Hydrogen Peroxide

Some physical constants of pure hydrogen peroxide have been reported as the following:—

Specific Gravity 0°/4°C. = 1,458—1.465
Melting Point = —0.89°C.
Latent Heat of Fusion = 2.5 Cal./mol.
Boiling Point = 155.5°C. @ 760 mm.
Heat of Vaporization = 11.6 Cal./mol.
Specific Conductivity = 2.10^{-6} ohms
Dielectric Constant = 73.2

Pure hydrogen peroxide is not a commercial commodity. This chemical is marketed as aqueous solutions of different strengths. When hydrogen peroxide first appeared on the market about a hundred years ago it was supplied in small, brown glass bottles in approximately 3% solution, primarily for medicinal use. Other specialty uses, such as the bleaching of hair in the beauty parlor trade, came into practice as somewhat higher strength solutions (5-6%) were made commercially available. Early in the twentieth century, with a further increase in strength to about 8% from U. S. production, and with the importation of hydrogen peroxide in concentrations up to 27.5%, this chemical made an entry into somewhat wider fields.

The introduction of the electrolytic processes for the production of hydrogen peroxide into the U. S. in 1920-1927 and the marked improvement in the stability of hydrogen peroxide and the development of aluminum containers for handling and shipping hydrogen peroxide in 1930-1932, have carried in their wake the production and marketing of hydrogen peroxide in higher strengths. By about 1928 the bulk of the U. S. production was being delivered to the trade at a concentration of 27.5%; since about 1940 the 27.5% product has been succeeded gradually by a 35% product. During the past few years a 50% product has been made available for commercial distribution; for safety reasons a product more concentrated than about 50% will probably not find general use. For special uses hydrogen peroxide is available in commercial quantities in concentrations up to 90%.

The 35% solution contains 16.5% active oxygen; at 20°C. it has a density of 1.1327 and weighs 9.44 pounds per gallon. The 50% solution contains 23.5% active oxygen; at 20°C. it has a density of 1.1957 and weighs 9.97 pounds per gallon. The freezing points of 35% and 50% solutions of hydrogen peroxide are -32.7°C. and -50.2°C., respectively. Crystal formation starts at the freezing point but complete solidification does not occur until considerably lower temperatures are reached. Consequently, transportation and storage in winter has offered no difficulties from freezing. In the concentrated form, hydrogen peroxide must be kept free from contamination since traces of catalytic metals cause accelerated decomposition. It should be stored in the original aluminum containers or in specially prepared aluminum tanks. If concentrated hydrogen peroxide is allowed to remain in contact with readily oxidizable organic materials, spontaneous combustion may occur.

Reactions of Hydrogen Peroxide

Hydrogen peroxide is a moderately strong oxidizing agent, a property which is the basis for many of its commercial applications. It oxidizes ferrous iron to ferric iron, nitrites to nitrates, sulfides and sulfites to sulfates, halogen acids to the corresponding halogens, alcohols and aldehydes to organic acids and even to carbon dioxide in the presence of certain catalysts. Hydrogen peroxide can be used

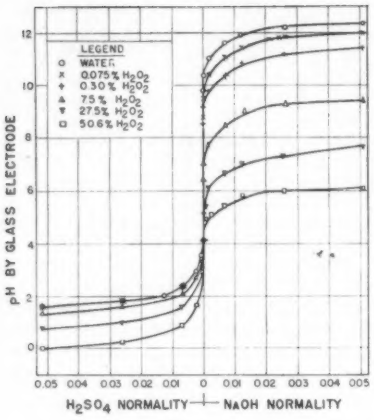


FIGURE 1
EFFECT OF HYDROGEN PEROXIDE CONCENTRATION ON THE pH OF PEROXIDE SOLUTIONS

as an oxidizing agent in acid, neutral, or alkaline solution. It has the unique advantage of producing only water as the by-product in oxidation reactions.

In contrast to its oxidizing properties, hydrogen peroxide also has a reducing action under some conditions; e.g., it reduces cupric salts, silver and gold oxides, vanadic acid, periodates, bromates and permanganates, oxygen generally being liberated in the reaction.

Being both an oxidizing and a reducing agent, hydrogen peroxide adapts itself to a wide variety of techniques in commercial processing. The rate and type of reaction can be controlled and directed by proper selection of pH, stabilizer, catalyst and temperature conditions, and by the use of buffers, such as silicates, phosphates, borates, or carbonates, to maintain the pH at the proper level.

Hydrogen peroxide adds to ethylenic hydrocarbons with the formation of dihydric alcohols; this reaction is promoted by first converting the hydrogen peroxide to performic or peracetic acid. Hydrogen peroxide is an active catalyst for hydrolysis and polymerization reactions. With many of the inorganic oxides and hydroxides it forms the corresponding peroxides, e.g., zinc, calcium, and magnesium peroxides. Most hydrate-forming salts produce perhydrates with hydrogen peroxide, e.g., sodium perborate ($NaBO_2.H_2O_2.3H_2O$), sodium percarbonate ($Na_2CO_3.1\text{-}\frac{1}{2}\,H_2O_2$), urea peroxide ($(NH_2)_2CO.H_2O_2$), and sodium perpyrophosphate ($Na_4P_2O_7.2H_2O_2$). Organic acid chlorides form organic peroxides; for example, benzoyl chloride with alkaline peroxide forms benzoyl peroxide. Organic acid anhydrides form the corresponding peracids.

Hydrogen peroxide also plays an interesting role in many biochemical reactions. In plant life it is probably an intermediate in the conversion of carbon dioxide from the air into carbohydrates and oxygen. In both plant and animal life hydrogen peroxide is intimately concerned with enzyme reactions, e.g., oxidase, peroxidase and catalase. It has a mild bactericidal action; in anaerobic infections it acts as a bacteriostat by maintaining a threshold concentration of oxygen. It promotes seed germination and yeast growth.

Analytical Methods

Active oxygen in peroxide solutions may be determined by three general methods:

(1) *By titration* with permanganate, iodine-thiosulfate, ceric sulfate or sodium nitrate; (2) *Gasometrically* by measuring the oxygen evolved on complete decomposition; and (3) *Colorimetrically* with titanium trichloride or ferric thiocyanate. Organic matter interferes with the permanganate methods; ortho-phenanthroline indicator gives a more definite endpoint with permanganate. Ammonium molybdate accelerates the KI-thio reaction; unsaturated compounds interfere with it. Ceric sulfate is less sensitive to organic matter than permanganate; here again the ortho-phenanthroline indicator is helpful. In the potentiometric titration of active oxygen, sodium nitrite shows a sharp change of 150-200 millivolts at the endpoint; it is not sensitive to organic compounds and is not influenced by coloring matter. Gasometric methods are used when oxidizing agents other than peroxide are present. Colorimetric methods are applicable for determining traces of active oxygen.

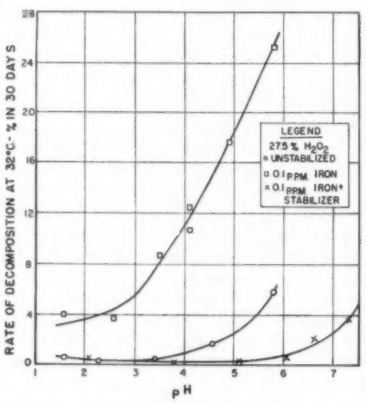


FIGURE 2
EFFECT OF CATALYST AND STABILIZER ON THE STABILITY OF HYDROGEN PEROXIDE

Control of pH in Peroxide Solutions

Peroxygen compounds vary in their behavior with the pH of the solutions in which they are employed. The methods available for measuring and controlling the pH of oxidizing solutions are contributing markedly to the development of the chemistry of peroxygen compounds and to the extension of their commercial applications. In processes employing a peroxide, pH control has become fully as important as control of temperature, time, and concentration.

The pH of peroxide solutions has an important bearing on peroxide stability. Peroxides are most stable in acid solutions and their rate of decomposition increases with the hydroxyl-ion concentration. Stability is furthermore influenced by inhibitors and catalysts whose activity depends upon the pH of the peroxide solution.

Rate and degree of bleaching with peroxides depend largely on the pH maintained in the bleaching processes. The catalytic effect of peroxides on hydrolytic reactions may be inhibited or accelerated by pH control. Rates of corrosion of structural materials are affected by changes in pH. In general, the desired properties of the peroxygen compounds can be promoted and their undesirable reactions can be repressed by proper pH control.

Some of the colorimetric pH indicators are affected by oxidizing compounds. However, with a proper choice of indicators, colorimetric methods can be applied satisfactorily in many cases. Among the potentiometric methods for determining pH, the hydrogen electrode, the quinhydrone electrode, and the metal-metal ion electrode, such as the antimony electrode, are subject to large errors in the presence of oxidizing agents. The glass electrode is well adapted to potentiometric pH measurements in oxidizing and reducing systems, and is suitable for determining the pH of peroxide solutions. It has the advantage over colorimetric methods that it can be employed successfully in highly colored or turbid solutions.

The system of curves in *Figure 1* shows the relationship between normality and pH at different peroxide concentrations. These curves illustrate

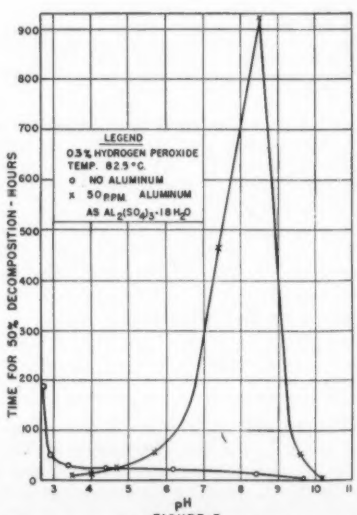


FIGURE 3
EFFECT OF ALUMINUM SALTS ON HYDROGEN PEROXIDE STABILITY

the weakly acid property of hydrogen peroxide. In the alkaline range the pH decreases with increase in peroxide concentration at a fixed sodium hydroxide concentration.

In the acid range the pH of the solution is lowered abnormally as the peroxide concentration is increased. With complete dissociation and an activity coefficient of 1, the calculated pH is 1.3 at an acid concentration of 0.05 N. A 50.6 percent hydrogen peroxide solution showed a measured pH of 0.0 at a sulfuric acid concentration of 0.05 N. A dissociation constant of 2.4×10^{-12} for hydrogen peroxide at 25°C. is not sufficient to account for this lowering in the observed pH value.

The dielectric constants for hydrogen peroxide solutions are considerably greater than the dielectric constant for water. Hence, the ionizing power of peroxide solutions may be greater than that of water, and this might be expected to result in an increased hydrogen-ion activity. These curves show an increased hydrogen-ion activity for sulfuric acid dissolved in aqueous solutions of hydrogen peroxide.

Stability of Peroxide Solutions

Pure solutions of hydrogen peroxide are inherently very stable. However, hydrogen peroxide is extremely susceptible to catalysts which decompose it into water and oxygen. Many metals, such as iron, copper and manganese, in concentrations as low as parts per billion, have a marked adverse effect on the stability of hydrogen peroxide. Stabilizers act as anti-catalysts. They may be classified functionally into three groups, namely (a) stabilizers which deactivate the metal ions by converting them into undissociated complexes, e.g., salicylic acid; (b) stabilizers which deactivate metal ions by colloidal adsorption, e.g., magnesium salts; and (c) chain breakers, such as phenolic compounds.

Some stabilizers are temporary in their effect; they are hydrolyzed or oxidized to ineffective reaction products, e.g., acetanilide is a very effective stabilizer at the start but is gradually hydrolyzed to acetic acid and aniline, and the aniline is then oxidized to nitrobenzene; hence the characteristic yellow color and the shoe polish odor of some drug store grades of hydrogen peroxide stabilized with acetanilide.

Other stabilizers continue to exert their stabilizing function indefinitely, e.g., metastannic acid which is not susceptible to oxidation or hydrolysis in peroxide solution. Among the thousands of compounds evaluated in our laboratories for stabilizing characteristics, a number of metal compounds have shown a most interesting behavior.

Researches on decomposition catalysts and on stabilizers for hydrogen peroxide have led to the manufacture of a product which is very stable, not only under normal storage conditions but also at elevated temperatures. The commercial product of twenty years ago generally decomposed to the extent of 30-100 percent when heated to 100°C. for 15 hours, whereas an improved product, showing losses of 0.2 percent or less under the same testing conditions, is now commercially available. As an illustration of its stability, a shipment of this improved grade of hydrogen peroxide showed a negligible loss in strength when stored in commercial containers in a representative warehouse in the South for over 8 years.

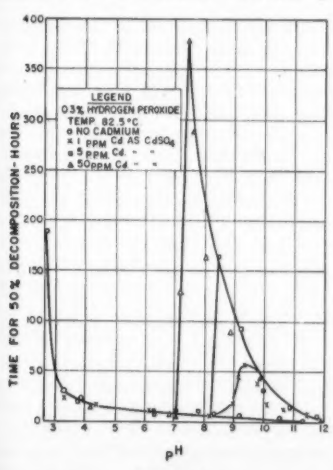


FIGURE 4

EFFECT OF CADMIUM SALTS ON HYDROGEN PEROXIDE STABILITY

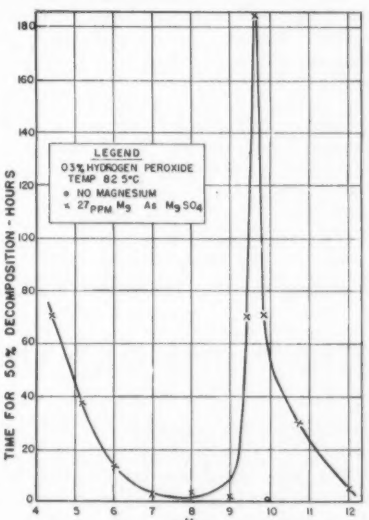


FIGURE 5

EFFECT OF MAGNESIUM SALTS ON HYDROGEN PEROXIDE STABILITY

Figure 2 shows how the rate of decomposition of hydrogen peroxide is accelerated by a metal catalyst like iron. It, furthermore, shows how the catalytic effect of iron can be inhibited by a stabilizer.

Figure 3 shows how, over a limited range of pH, the stability of peroxide solutions is improved by aluminum salts.

Figure 4, showing the stabilizing effect of cadmium salts, is interesting in that an increase in cadmium concentration not only increases the magnitude of stabilizing action but also widens the pH range of stabilization.

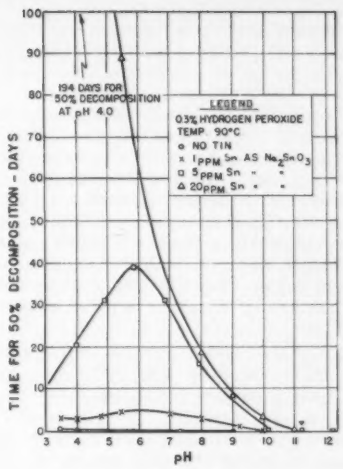


FIGURE 6

EFFECT OF TIN SALTS ON HYDROGEN PEROXIDE STABILITY

Figure 5 shows the stabilizing effect magnesium salts. This stabilizing action of magnesium is of particular interest in pulp bleaching applications because it is most effective in the pH range where peroxide is most effective for pulp bleaching.

Figure 6 shows the exceptionally high stabilizing action of tin compounds. Please note that in this curve the time is expressed in days, while in the preceding curves for aluminum, cadmium and magnesium, the time is expressed in hours.

Shipping Containers

"Solozone" sodium peroxide is shipped in steel drums containing 400 lbs. net. To facilitate emptying "Solozone" drums, a convenient device which includes a sling, tilter, hopper, and discharge valve is used. "Solozone" is also available in 75 lb. net pails for smaller users.

"Albone" 35 and 50 hydrogen peroxide are shipped in aluminum drums containing 250 lbs. net, in aluminum tank trucks and in aluminum tank cars containing 32,000, 57,000 and 76,000 lbs. net. Emptying devices, including a valve and drum tilter, are available for "Albone" drums. A typical layout for bulk handling and storage of hydrogen peroxide is shown in *Figure 7*.

Uses of Peroxides

Commercial uses for peroxides are showing a healthy growth, due largely to extensive and continued research and development work on these products. A better understanding of the chemistry of peroxides has led to improvements in the quality of the products, to better methods of shipping and handling, to improved techniques and closer control in peroxide-consuming processes, to a wider choice in

structural materials, and to the application of good engineering principles in the layout of equipment for operating peroxide-consuming processes.

Peroxides are used extensively in bleaching operations. Peroxide solutions have distinct advantages in textile bleaching: uniform bleaching with permanent whiteness, exceptionally low losses in fiber strength, freedom from dye resists, and improved appearance, feel, loft, and elasticity. Cotton, wool, linen, rayon, silk, and mixed fibers are satisfactorily bleached with hydrogen peroxide.

Development of a continuous cotton bleaching process has expanded the utilization of peroxide in this field. By this process bleaching is completed in 2 hours as compared with the 8 to 24 hours required for kier bleaching. In addition to speed of operation, this process has the advantage of lower operating costs and improved uniformity in color, appearance, and absorbency.

Many other materials are bleached with peroxide to improve their utility. A partial list includes: straw for the manufacture of hats; fur for preparing white furs or for dyeing to various colors; pearl, bone, and plastic buttons; wood for furniture, tool handles, and athletic equipment such as baseball bats and tennis rackets; vegetable oils for edible products; lecithin extracted from soybean protein for use as an emulsifier in the production of food products; lanolin, beeswax, and sulfonated oils for salves and ointments; sausage casings; and sponges.

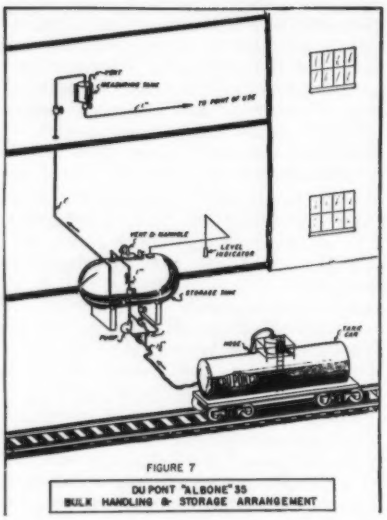


FIGURE 7
DU PONT "ALBONE" 35
BULK HANDLING & STORAGE ARRANGEMENT

Vat dyeing of textiles is facilitated by using peroxide as the oxidizing agent. In the manufacture of felt hats the fur is carroted with hydrogen peroxide to develop the necessary felting properties. In the production of adhesives and coating materials from products such as starch, soybean protein, and nitrocellulose, hydrogen peroxide reduces the viscosity of these materials so they can be applied in higher concentrations.

The critical situation with regard to some metals and metal salts is alleviated somewhat through the use of peroxide. The effective removal of iron from metal salt solutions makes it possible to use lower grade raw materials in many instances. In the deironing process, ferrous iron is oxidized to ferric iron with peroxide; the ferric iron is then removed by adjusting the pH of the solution to the proper value and precipitating the iron either as the insoluble hydroxide or by coprecipitation with other reagents. Copper, zinc, nickel, manganese, and aluminum solutions can be purified in this way.

In the production of corrosion-resistant coatings on metals, peroxide is used as a constituent of metal-plating baths; it aids in elimination of porosity and, in certain instances, improves the brightness of electroplated coatings.

Peroxide is used as the oxidizing agent in the manufacture of dyes, sulfur chemicals for the rubber industry, and medicinals and pharmaceuticals. It functions as a polymerization catalyst in the production of synthetic rubbers, resins, and plastics. Hydrogen peroxide has advantages over other oxidizing agents for developing blueprints, since no residual chemicals are left in the bath and a sharper contrast between white lines and blue background is produced.

During the past decade peroxides were introduced into the field of pulp bleaching. This comparatively new peroxide application will be discussed in the next part.

PART II—APPLICATIONS IN THE PULP AND PAPER INDUSTRY

I. Introduction

In the fall of 1950, I had the privilege of presenting a status report on "Peroxide Bleaching of Groundwood" at the dedication of the new Science Building at Colby College. I must ask those of you who were present on that occasion to bear with me this morning, since of necessity there will be some duplication in subject matter.

II. Commercial Status

Over the past two years peroxide bleaching of groundwood has expanded materially and is now in commercial operation in 24 mills with a total capacity of about 1,250 tons per day. Additional bleacheries are being installed and will be put into operation in the course of this year. Most of the bleacheries are being operated in completely integrated pulp and paper mills. However, three groundwood mills have started producing peroxide bleached groundwood for delivery to non-integrated paper mills; there is a ready market for the bleached product. Several mills are bleaching mixtures of groundwood and sulfite pulp; under some conditions, e.g., in mills where the entire paper production is one grade or closely allied grades, this procedure has operating advantages.

Peroxide bleached groundwood is being used to advantage in the production of a range of papers, i.e., papers in which moderate strength, brightness and color stability, with good opacity, bulk, cleanliness, absorbency and printing properties are desirable. Fields of application include book, magazine, tissue, towelling, napkins, directory, catalog, mimeo, tablet and a number of specialty papers.

III. Chemicals

The chemicals used in the bleaching process are hydrogen peroxide or sodium peroxide or both, sodium silicate, sulfuric acid or caustic soda, magnesium sulfate, and a reducing and neutralizing agent, such as sulfur dioxide, sulfite cooking acid, sodium metabisulfite, sodium bisulfite or sodium thiosulfate.

Peroxides—The peroxides were discussed in the preceding session. As a source of active oxygen, hydrogen peroxide and sodium peroxide are interchangeable. One pound of sodium peroxide is equivalent in active oxygen content to 1.21 pounds of 35 percent hydrogen peroxide or 0.85 pound of 50 percent hydrogen peroxide, plus 1.02 pounds of caustic soda. In some pulp bleaching processes, such as bleaching of groundwood with low percentages of peroxide (e.g. 1 percent), or deinking of waste papers with peroxide, the full alkali value of sodium peroxide can be utilized.

For groundwood bleaching operations in general, the alkali content of sodium peroxide exceeds the amount required for best results. In preparing the bleaching solution for these operations, with sodium peroxide as the sole source of active oxygen, the alkali supplied by sodium peroxide must be partly neutralized. This is done most economically with sulfuric acid. Hydrogen peroxide, on the contrary, is slightly acid in character. Consequently, when the bleaching solution is prepared with hydrogen peroxide as the sole source of active oxygen, some caustic soda or other alkali must be used to provide the required alkalinity. By using hydrogen peroxide and sodium peroxide in the proper proportions in preparing the bleaching solution, the use of both sulfuric acid and caustic soda can be eliminated.

Sodium Silicate—For use in this process sodium silicate should be water-white and as free as possible from heavy metal impurities; it should have no adverse effect on the stability of peroxide solutions. Silicate solutions are shipped in 55 gallon steel drums and in steel tank cars; solid silicates are handled in bulk or bag carload shipments and require special dissolving equipment. Since sodium peroxide and sodium silicate together supply more than the amount of alkali required for the process, the value of the silicate lies principally in its SiO_2 content rather than in its Na_2O content. When hydrogen peroxide is used as the bleaching agent, the required amount of alkali may be supplied by the addition of caustic soda plus sodium silicate or by the addition of sufficient silicate alone.

Sodium silicate has the properties of a detergent and a penetrant. It buffers the bleaching solution and aids in maintaining the pH in the desired range. It forms a protective coating on the surface of metals and inhibits corrosion of metal equipment. It also has a stabilizing action on peroxide solutions under the conditions which prevail in the pulp bleaching process. The amount of silicate used in the bleaching process does not appear to be critical; 5 percent of sodium silicate (41.5° Be containing 29 percent SiO_2 and 8.9 percent Na_2O), based on the moisure free weight of the pulp, has proved satisfactory in most pulp bleaching operations. Silicates with other compositions may be used with proper modifications in the preparation of the bleaching solution.

Sulfuric Acid—A clear, colorless grade of 66° Be sulfuric acid is preferred. This chemical is shipped in 200 pound glass carboys, steel drums, and steel tank cars. For good bleaching results the total alkali content of the bleaching solution must be controlled within proper limits. Sodium peroxide and sodium silicate are alkaline; in general, part of the alkali introduced into the bleaching solution by these chemicals must be neutralized with sulfuric acid. If hydrogen peroxide is used as the bleaching agent, sulfuric acid is not required.

Caustic Soda—A clear grade of liquid caustic soda is preferred; it is shipped in tank cars at 50 percent and 73 percent concentrations. This chemical is useful in controlling the total alkalinity of the bleaching solution prepared from hydrogen peroxide. The use of caustic soda is the most economical means of supplying this needed alkali although extra amounts of sodium silicate, i.e., over that normally required for stability and buffering, may be used.

Magnesium Sulfate—This chemical is available as the hydrated crystalline salt ($MgSO_4.7H_2O$ — Epsom Salt). Magnesium sulfate has a remarkable stabilizing effect on alkaline peroxide solutions under the conditions which prevail in pulp bleaching processes. It performs this function by inhibiting the catalytic effects of the traces of metals, particularly iron, copper, and manganese, which are commonly present in pulpwood and in mill waters. The stabilizing effect is obtained with small amounts of magnesium sulfate, e.g., about one pound of Epsom Salt per 500 gallons of bleaching solution. In some instances where additional stability in the bleaching operation is desirable, a small amount of magnesium sulfate is added directly to the stock before it is mixed with the bleaching solution.

Neutralizing and Reducing Agent — In mills which produce both groundwood and sulfite pulps, sulfite cooking acid is a convenient and economical material for the neutralizing and reducing treathment in the final step in the process. The sulfite cooking acid should be low in heavy metal content and should be free from organic coloring matter, dirt, and sludge; it is desirable to remove any colored solids from the sulfite cooking acid in a small sand filter.

Other reducing agents, such as sulfur dioxide, sodium bisulfite, sodium metabisulfite, sodium thiosulfate, sodium hydrosulfite or zinc hydrosulfite, will also function satisfactorily as the reducing agent. It may be necessary in some instances to use an acidic material, such as sulfuric acid or alum, for lowering the pH to the desired value.

Reducing agents of this type have several desirable effects in the final stage treatment of the bleached pulp. They neutralize the small amount of alkali remaining in the pulp at the end of the peroxide bleaching step and lower the pH of the pulp to the desired value. They reduce to the colorless ferrous form the traces of highly colored ferric iron normally present in the bleached pulp. They also destroy the trace of peroxide remaining in the pulp and prevent the development of a pink color which frequently results when unbleached sulfite pulp is mixed with bleached groundwood containing traces of residual peroxide.

IV. Chemistry of Peroxide Bleaching

The hypothesis that peroxides in a bleaching reaction must decompose to form water and nascent or atomic oxygen, the latter being the active bleaching agent, has given way to a newer concept of the reaction. The modern concept of the mechanism of peroxide bleaching, which is now quite generally accepted, postulates the dissociation of the peroxide into ions. The ionization of hydrogen peroxide may be expressed as follows:

$$H_2O_2 \longleftarrow\!\!\!\!\!\!\longrightarrow H^+ + HO^-_2$$

The HO^-_2 iron is considered to be the active bleaching agent. The formation of HO^-_2 irons is promoted by neutralizing the H^+ ions with an alkali, as would be expected from the Law of Mass Action; conversely, the reaction may be reversed by addition of an acid (H^+ ions).

Under adverse conditions hydrogen peroxide decomposes into water and oxygen gas, according to the following equation:

$$2H_2O_2 \longrightarrow 2H_2O + O_2$$

The wasteful decomposition of hydrogen peroxide is promoted by metal catalysts (notably copper, iron and managanese); the catalytic effect of heavy metals is retarded by stabilizing agents.

Little is known about the nature of the chemical reactions involved in the bleaching of wood pulps with peroxide. It has been suggested that the action of peroxide on pulp is a selective oxidation and/or hydrolysis of some of the traces of organic coloring matter naturally present in the wood. The fact that cellulose and lignin undergo little or no change during the peroxide bleaching process lends weight to this hypothesis.

V. The Bleaching Process

Bleaching groundwood with peroxide is a simple process which includes four basic operations, namely:

a. Preparing the bleaching solution

b. Rapid and thorough mixing of the peroxide bleaching solution with the pulp in controlled proportions.

c. Retaining the peroxide treated pulp long enough to permit the bleaching to go to completion.

d. Reducing the residual peroxide and neutralizing the bleached pulp to the pH desired for the paper furnish.

In a typical operation of this process, the peroxide bleaching solution is prepared in a dissolving tank equipped for vigorous agitation. The tank is charged with water. A small amount of magnesium sulfate is first dissolved in the water, followed in order by the required amounts of sodium silicate and peroxide. If hydrogen peroxide and sodium peroxide are used in the proper proportions, no further chemicals, i.e., alkali or acid, are required. When hydrogen peroxide is the sole source of active oxygen some additional alkali must be added, whereas with sodium peroxide it will be necessary to add some acid.

The unbleached groundwood is metered to the system at a controlled consistency, thickened, and heated if necessary. The pulp and the peroxide bleaching solution are then throughly mixed in controlled proportions and held in a continuous retention tower or in multiple holding chests where the bleaching reaction goes to completion. The bleached pulp is neutralized and the residual peroxide is reduced by a treatment with sulfur dioxide after which it is ready for the paper machine furnish.

The preferred type of bleaching equipment and procedure depend to a large extent upon the quantities of pulp to be bleached, the equipment already available in the mill, and other local variables.

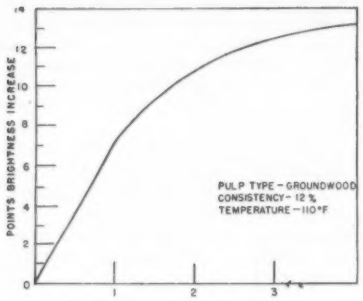

POINTS BRIGHTNESS INCREASE
PULP TYPE – GROUNDWOOD
CONSISTENCY – 12 %
TEMPERATURE – 110°F
% SODIUM PEROXIDE ON MOISTURE FREE PULP

FIG. 1
BRIGHTNESS INCREASE WITH INCREASING AMOUNTS OF SODIUM PEROXIDE

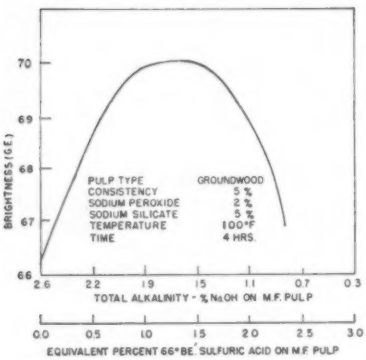

BRIGHTNESS (G.E.)
PULP TYPE GROUNDWOOD
CONSISTENCY 5 %
SODIUM PEROXIDE 2 %
SODIUM SILICATE 5 %
TEMPERATURE 100°F
TIME 4 HRS.
TOTAL ALKALINITY - % NaOH ON M.F. PULP
EQUIVALENT PERCENT 66°BE. SULFURIC ACID ON M.F. PULP

FIG. 2
EFFECT OF ALKALINITY ON BRIGHTNESS OF BLEACHED PULP

VI. Variables in the Bleaching Process

a. Process Variables—The chemistry of the peroxide bleaching process is not thoroughly understood; however, an extensive program of laboratory investigations and a wide experience in commercial mill operations have produced a good working knowledge of the variables in the groundwood bleaching process. Many of these variables are interdependent; i.e., a change in one variable necessitates a change in one or more other variables. However, while it is not possible to predict the exact requirements for a specific case, most of the variables may be closely defined.

Percentage of Peroxide Used in Bleaching—Economic considerations and brightness requirements will normally dictate the amount of peroxide to be used. From an efficiency standpoint, the range of 1-2 percent commercial strength hydrogen peroxide (or its active oxygen equivalent in sodium peroxide) based on the weight of the pulp appears to be most practical. *Figure 1* shows the brightness increases normally obtained with increasing percentages of peroxide.

Alkalinity— The alkalinity and pH of the peroxide bleaching solution may be varied by the addition of sulfuric acid, sodium silicate or caustic soda. For a maximum brightness increase and a minimum bleaching time, the groundwood after adding the bleaching solution should have a pH value between 10.0 and 10.5.

The total alkali, calculated as NaOH, will at the start fall between the limits of 1.2-1. percent based on the moisture-free weight of pulp. The higher alkali value is preferable for bleaching at a low consistency and a low temperature whereas the lower alkali value is desirable for bleaching at higher consistencies and higher temperatures. As shown in *Figure 2* the alkalinity must be controlled within definite limits to obtain the maximum brightness increase.

Bleaching Temperature— At a constant consistency the time required to obtain the maximum brightness increase depends principally on the temperature at which the bleaching is carried out. In general, the bleaching time increases about two-fold for every 18°F. (10°C.) drop in temperature. As an illustration, bleaching at 5 percent consistency and 90°F. requires 5 to 6 hours for completion whereas at 115°F. the bleaching will be substantially complete in about 3 hours. The relation between bleaching temperature and bleaching time is shown in *Figure 3*. The preferred temperature of about 100-150°F. is within the range generally prevalent in integrated mills. At lower temperatures a longer bleaching time necessitates larger bleaching towers or chests; at higher temperatures the bleaching time requires closer control.

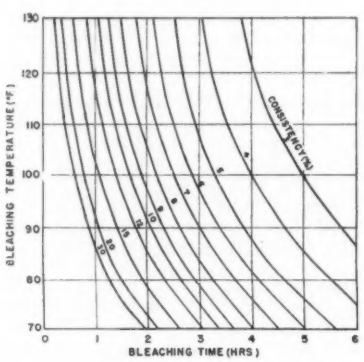


FIG. 3
PEROXIDE BLEACHING OF GROUNDWOOD
EFFECT OF TEMPERATURE AND CONSISTENCY ON BLEACHING TIME

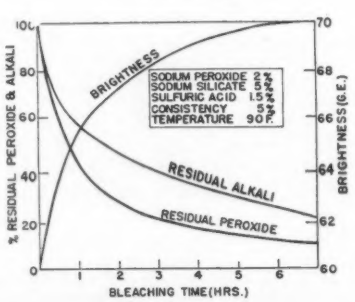


FIG. 4
INCREASE IN BRIGHTNESS AND DECREASE IN PEROXIDE AND ALKALI CONCENTRATIONS DURING BLEACHING CYCLE

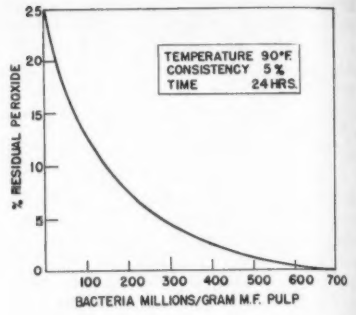


FIG. 5
RELATION BETWEEN BACTERIA COUNT AND STABILITY OF PEROXIDE BLEACHING SOLUTION IN GROUNDWOOD SLURRY

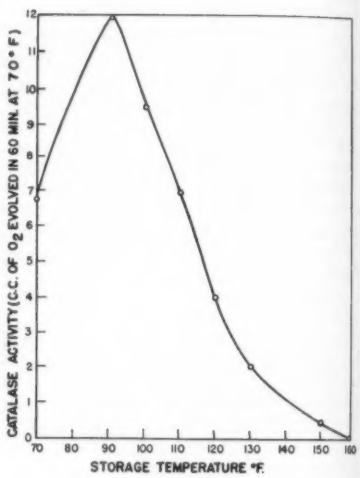


FIGURE 6
EFFECT OF ONE HOUR STORAGE PERIOD ON THE CATALASE ACTIVITY OF THE GROUNDWOOD

Bleaching Time—The time for completing the bleaching process is dependent on the variables previously described. The progressive increase in brightness during the bleaching period is shown in *Figure 4*. This figure also shows the rate of consumption of alkali and peroxide.

Reducing and Neutralizing Treatment — This operation, applied to the pulp after bleaching, is conveniently accomplished at a low consistency, i.e., 3-5 percent. Sulfur dioxide is most widely used for this treatment; filtered sulfite acid and sodium metabisulfite are also suitable for this purpose. Ordinarily when sufficient reducing agent is added to lower the pH of the pulp to a value of 6-7, the residual peroxide will be completely destroyed. With good agitation, this reaction is completed almost instantly. In some cases, when bleached pulp with a low pH value is desired, it may be more economical to use a minimum amount of reducing agent and neutralize to the desired pH with sulfuric acid or alum.

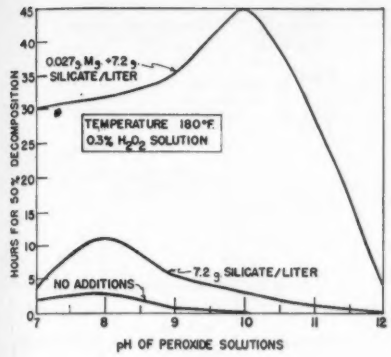


FIG. 7
EFFECTS OF MAGNESIUM SULFATE AND SODIUM SILICATE ON THE STABILITY OF PEROXIDE SOLUTIONS

b. Variables in the Raw Materials

Species of Wood—The bleachability of groundwood varies somewhat with the different species of wood. Spruce, balsam, fir, Douglas fir, some kinds of poplar, southern yellow pine, basswood and birch are known to respond favorably to peroxide bleaching. A study of the bleachability of other species of woods is in progress.

Age of Pulp—In general, somewhat greater brightness increases are obtained when groundwood is bleached immediately after grinding. However, good bleaching results have been obtained with groundwood stored for six months and longer. Molding and spoilage of pulp during storage has an adverse effect on bleaching results.

Bacteria and Enzymes—Mechanical pulps are particularly susceptible to bacteria, algae, and fungus growths. The conditions in groundwood mill waters and in groundwood slurries are generally favorable for their development. Many strains of bacteria present in groundwood systems are in the enzyme-generating class. Among the enzymes produced in the metabolism of bacteria is the enzyme catalase. This enzyme is characterized by the property of accelerating peroxide decomposition. The effect of catalase generated by bacterial metabolism on the rate of peroxide decomposition in a typical groundwood slurry is shown in *Figure 5*. The data presented in *Figure 6* show that catalase activity increases with temperature up to 90°F. and then gradually decreases, until at 160°F. the catalase is destroyed.

Groundwood containing excessive amounts of bacteria and catalase will not react favorably to peroxide bleaching. Groundwood having a bacteria count of approximately 100 million or less per gram of moisture-free pulp will react normally to peroxide bleaching. Bacteria and enzymes can be controlled by heat, chlorinating agents, oxidizing agents and other bactericides. With good mill practice in slime control it is not likely that tolerable concentrations of bacteria and enzymes will be exceeded.

Quality of Water—Water of good quality is an important factor in the production and bleaching of mechanical pulps and also in the conversion of the pulps into paper. Good water is a particularly important factor in the production of bright papers. Colored impurities or color-producing impurities, such as the highly-colored iron compounds, cause substantial drops in pulp and paper brightnesses. Under adverse water conditions decreases as great as 14 points in brightness have been observed between the grinder pit and the deckered stock.

Many of the heavy metals, particularly iron, copper, and manganese have a catalytic effect on the decomposition of peroxide. These metals, normally present in pulpwood and in mill waters, may be in an active form or they may be chemically combined with other constituents of the wood or water in an inactive form. The

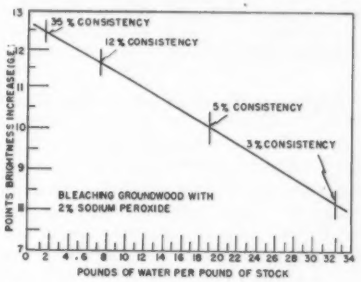

35 % CONSISTENCY
12 % CONSISTENCY
5% CONSISTENCY
3 % CONSISTENCY
BLEACHING GROUNDWOOD WITH 2% SODIUM PEROXIDE
POINTS BRIGHTNESS INCREASE (GE)
POUNDS OF WATER PER POUND OF STOCK

FIG. 8
EFFECT OF CONSISTENCY ON BRIGHTNESS GAIN UNDER FAVORABLE CONDITIONS

traces of catalytic metals in pulpwood are comparatively inactive; they are probably tied up as undissociated complexes with organic compounds in the wood; also, their catalytic activity is inhibited by the stabilizing compounds of magnesium and calcium compounds present in the pulpwood. The catalytic metals in the mill waters are likely to be in an active form and are more apt to have an adverse effect on the bleaching results, unless steps are taken to deactivate them. Deactivation of these metal catalysts may be accomplished by the addition of magnesium sulfate to the bleaching solution, to the pulp, or to both. The stabilizing effects of megnesium sulfate and sodium silicate are shown in *Figure 7*.

Pulp Consistency—*Figure 8* shows the effect of pulp consistency on bleaching efficiency. Pulp consistency, expressed as pounds of water per pound of stock, plotted against brightness gain, shows approximately a straight line relationship. In the consistency range between 3 percent and 35 percent there is a steady increase in brightness gain as the pulp is thickened to higher consistencies.

The problem of processing groundwood and other pulps at the higher consistencies is being approached from at least two directions. In one direction, new types of equipment are being perfected for dewatering the pulp to a high consistency for mixing the high consistency pulp in the processing. In another direction progress is being made on applying the bleaching solution to the pulp in sheet form at a high consistency.

In the choice of an installation for peroxide bleaching of groundwood, important factors other than consistency must receive consideration, e.g., production rate, and equipment adaptable to the process already available in the mill.

From the standpoint of consistency, the groundwood bleacheries now in operation classify themselves approximately as follows:—

Consistency	Bleaching Capacity Tons/Day	% of Total
Low (4-6%)	480	38
Medium (9-15%)	660	53
High (20-35%)	110	9
Total	1,250	100

VII. Preparing and Handling the Peroxide Bleaching Solution

Typical installations for preparing and handling the peroxide solution for bleaching groundwood are shown in the following figures.

Figure 9 shows the batch preparation of the peroxide bleaching solution from "Solozone" sodium peroxide. The dissolving tank, equipped for good agitation, is first charged with water. The chemicals are added in measured quantities in the following sequence:—(1) Epsom Salt (as a solid or in solution), (2) sodium silicate delivered from the storage tank, (3) sodium peroxide from drums with a special, convenient handling device, (4) sulfuric acid from the storage tank.

Figure 10 shows the batch preparation of the peroxide bleaching solution from hydrogen peroxide and sodium peroxide. In this procedure hydrogen peroxide and sodium peroxide are used in the proper proportions to provide the required amounts of active oxygen and alkali. The hydrogen peroxide, delivered in measured amounts from the storage tank, is introduced into the dissolving tank after adding the sodium peroxide. The so-

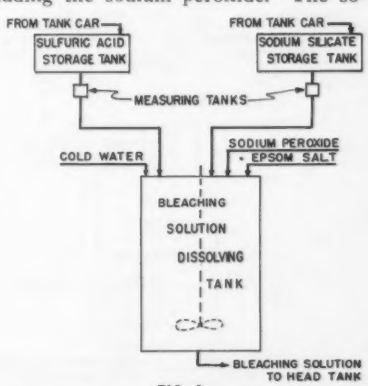


FIG. 9
BATCH PREPARATION OF THE BLEACHING SOLUTION FROM SODIUM PEROXIDE

dium peroxide is added directly from the original containers (400 lb. drums) by means of a convenient emptying device. No sulfuric acid is required in this procedure for preparing the peroxide bleaching solution.

Chemicals handling and chemicals costs are important factors in choosing the type of peroxide formula for preparing the bleaching solution. Both procedures, i.e., preparing the bleaching solution with sodium peroxide and sulfuric acid, as well as preparing it with a combination of hydrogen peroxide and sodium peroxide, are in wide commercial use.

Figure 11 shows the continuous preparation of the bleaching solution. In this procedure the chemicals are mixed continuously in a series of four small compartments. Epsom Salt and sodium silicate are dissolved in water in the first compartment. This solution overflows into the second compartment, where where the sodium peroxide is introduced. From the second compartment the solution in turn overflows into the third compartment where the sulfuric acid is added. From here the solution overflows into the fourth compartment and is delivered to a small supply tank.

By substituting hydrogen peroxide for the sulfuric acid in the third compartment, this procedure can probably be adapted for using the combination of hydrogen peroxide and sodium peroxide.

This equipment was first put into commercial operation in early 1950 and has been giving satisfactory performance.

VIII. Commercial Operation of the Process

Low Consistency (4-6%) Batch Bleaching Process—In this process as shown in *Figure 12* the deckered stock is mixed with the peroxide bleaching solution in an agitated chest, where the stock is held until the bleaching goes to completion. The peroxide treated stock is then neutralized with sulfur dioxide in a dilution chest and delivered to the bleached groundwood supply chest.

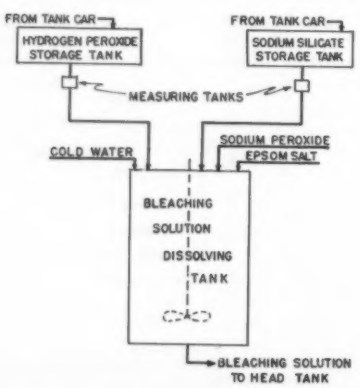


FIG. 10
BATCH PREPARATION OF THE BLEACHING SOLUTION FROM SODIUM PEROXIDE AND HYDROGEN PEROXIDE

Low Consistency (4-6%) Bleaching in Multiple Retention Tanks—The low consistency bleaching process can be made semi-continuous as shown in *Figure 13*. In this process three tanks are used in rotation for holding the peroxide-treated groundwood. While one of the tanks is being filled with peroxide-treated pulp, the stock in the second tank is standing to permit the bleaching to go to completion, and bleached stock is being drawn from the third tank through the neutralizing treatment and on into the bleached groundwood supply chest.

Continuous Bleaching at Low Consistency (4-6%)—The low consistency process can be made fully continuous as shown in *Figure 14*. In this process the peroxide-treated groundwood is pumped continuously into the bottom of a tower and overflows through a launder into a dilution chest where it is neutralized with sulfur dioxide. From this chest the bleached pulp drops into the bleached groundwood supply chest.

Continuous Bleaching at Medium Consistency (9-15%)—In this process shown in *Figure 15* the deckered stock is thickened to a consistency of 9-15 percent and mixed with the peroxide bleaching solution. The peroxide treated stock is dropped into the top of a tower with a bottom discharge. From the tower the bleached stock is conveyed to a dilution chest from which, after neutralization, it is delivered to the bleached pulp supply chest.

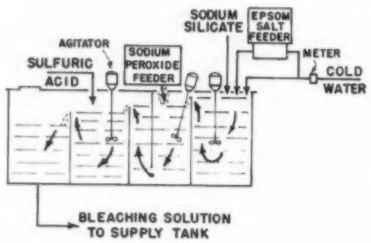


FIG. 11
CONTINUOUS PREPARATION OF THE BLEACHING SOLUTION FROM SODIUM PEROXIDE

Continuous Bleaching of Mixtures of Groundwood and Sulfite Pulps at Medium Consistency (9-15%)—As shown in *Figure 16* the medium consistency process has been adapted for bleaching mixtures of groundwood and sulfite pulps. In this procedure the two pulps are metered and delivered to the thickener in the desired proportions. The thickened stock, after mixing with the peroxide bleaching solution, is dropped into the top of a tower with a bottom discharge. From the tower the bleached stock is conveyed to the dilution chest from which, after neutralization, it is delivered to the bleached groundwood supply chest. This process is shown more graphically and in more detail in *Figure 17*.

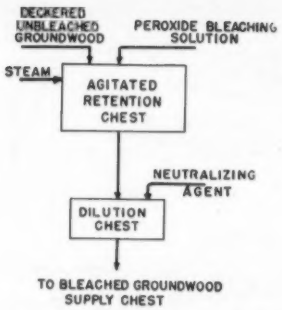


FIG. 12
LOW CONSISTENCY (4-6%) BATCH BLEACHING PROCESS

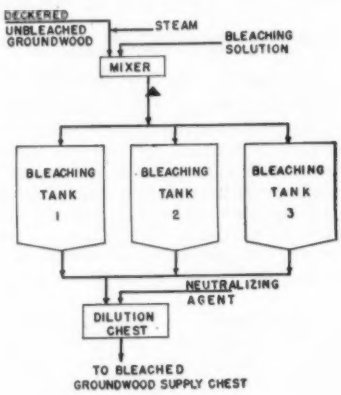


FIG. 13
LOW CONSISTENCY(4-6%)BLEACHING IN MULTIPLE RETENTION TANKS

Continuous Bleaching of Groundwood at High Consistency (20-35%)—In this process shown is *Figure 18* the deckered stock is dewatered in a pulp press and, after mixing with the bleaching solution, drops into the top of a tower with a bottom discharge. From the tower the stock is conveyed to the dilution chest and after neutralization is delivered to the bleached groundwood storage chest.

This process, as well as other high consistency bleaching processes, such as adding the bleaching solution to the pulper in a non-integrated mill or applying the bleaching solution to the pulp in sheet form, has an inherent advantage in chemical efficiency. However, both involve processing features which are open to further improvement.

Continuous Bleaching at Medium Consistency (9-15%) in Pulp Mills—In this medium consistency process shown in *Figure 19* the deckered groundwood is dewatered in a vacuum thickener and, after mixing with the peroxide bleaching solution, drops into the top of a tower with a bottom discharge. From the tower the stock is conveyed to a dilution chest and after neutralization is delivered to the wet machine. The laps are further dewatered under hydraulic pressure and baled for delivery to the consuming mill.

Batch Bleaching at Low Consistency

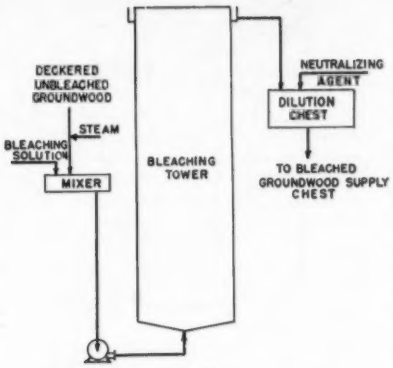


FIG. 14

LOW CONSISTENCY (4-6%) CONTINUOUS BLEACHING PROCESS

(4-6%) in a Non-Integrated Paper Mill — In this batch process shown in *Figure 20* the lapped groundwood from an outside source is pulped at a consistency of 4-6 percent and mixed with the peroxide bleaching solution. The peroxide-treated pulp is dropped into a retention chest, neutralized in a dilution chest and delivered to the bleached groundwood supply chest.

Continuous Bleaching at High Consistency (20-25%) in a Non-Integrated Paper Mill— As shown in *Figure 21* are lapped groundwood from an outside source is shredded and fed continuously into a high consistency pulper, where it is mixed with the peroxide bleaching solution. By maintaining an adequate temperature, the bleaching is completed in the pulper. The bleached stock is dropped into a dilution chest and, after neutralization, is delivered to the bleached groundwood suppily chest.

IX. Structural Materials

In the choice of structural materials for operating the peroxide bleaching process the following factors require consideration: (a) resistance to corrosion, (b) catalytic effect on peroxide decomposition, and (c) pulp discoloration. Stainless steel, tile-lined concrete and rubber-lined steel are generally applicable. "Transite" and wood are suitable for some applications. Lead and copper are active catalysts for peroxide decomposition and must be avoided in equipment which comes into contact with the peroxide bleaching solution or with the peroxide-treated pulp while bleaching is in progress. Iron is also a catalyst for peroxide decomposition, though not as active as copper and lead. In mills where the pulp or the mill waters are abnormally high in acidity, iron equipment is subject to corrosion. Dissolved iron causes a reversion in pulp brightness in any type of pulp and has an adverse effect on bleaching efficiency. Iron is not recommended for equipment which comes into contact with the bleaching solution; it is not a preferred structural material in contact with peroxide-treated pulp while bleaching is in progress, though ordinary iron will give fair performance for this operation if coated with silicate or some other corrosion-resistant material. Entry or lead, copper and iron into the pulp and mill waters should be avoided or kept to the minimum practical figure. Some kinds of wood (e.g., cyprus and yellow pine) are satisfactory under some conditions however, at high temperatures and/or high alkalinities, wood fibers tend to soften and swell, resulting in a short life.

Special consideration must be given to the choice of a suitable structural material for each specific application.

X. Characteristics of Peroxide Bleached Groundwood

Many of the basic properties of bleached groundwood depend upon the

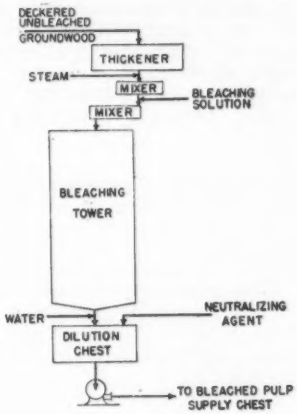


FIG.15

MEDIUM CONSISTENCY(9-15%)CONTINUOUS BLEACHING PROCESS

type of wood used and on the pulping procedure. It is well known that the proper species and quality of wood must be selected and that the wood must be seasoned to the right moisture content, well cleaned, and carefully ground with close control of temperature and stone surface, to give the desired properties as measured in bulk, freeness, strength, and opacity. Peroxide bleaching does not bring about substantial changes in these properties.

Brightness—Improvement in brightness is the most important result from the bleaching treatment. The brightness increase obtained in bleaching depends upon a number of factors, such as the species and condition of the wood, the brightness of the unbleached pulp, the percentage of peroxide used in bleaching and the bleaching conditions, notably, alkalinity, consistency, temperature and time of bleaching.

With groundwood at a higher brightness level it is possible to include a substantial percentage of groundwood in a paper furnish and still maintain a satisfactory paper brightness. The effect of an increase in groundwood brightness on the color of groundwood papers is accentuated by the opacity and covering power of groundwood as compared to the longer-fibered sulfite and sulfate pulps. Consequently, an increase in the brightness of the groundwood in a paper furnish results in greater increases in paper brightness than would be expected from averaging the brightness readings on the pulps used in the furnish.

Stability—The stability of groundwood to sunlight or the ultra-violet lamp is not improved to an appreciable degree by the bleaching treatment. Stored away from light the bleached pulp and also papers containing bleached groundwood are quite stable; a drop in brightness from 67.2 to 66.4 was observed in a storage test of over two years. Bleached groundwood shows good stability in heat drying over the paper machine. The loss in brightness usually encountered over the paper machine with unbleached groundwood is normally not encountered to the same degree with peroxide bleached groundwood.

Opacity—Since the bleaching treatment removes color from the pulp, a corresponding decrease in opacity is to be expected; this is true, however, only to a small degree. High percentages of bleached groundwood can be used in furnishes to produce papers in which the properties of high opacity and high brightness are combined. A 62 pound sheet containing 60 percent bleached groundwood is reported to have the same opacity as a 75 pound free sheet.

Bulk—The bulking properties as measured either in the pulp or in the paper are very nearly the same before and after bleaching.

Freeness—Groundwood gives about the same results in freeness tests before and after bleaching. While the freeness of groundwood is not appreciably changed by bleaching, nevertheless, the working properties are better and the drainage rate on the paper machine is higher with the bleached pulp.

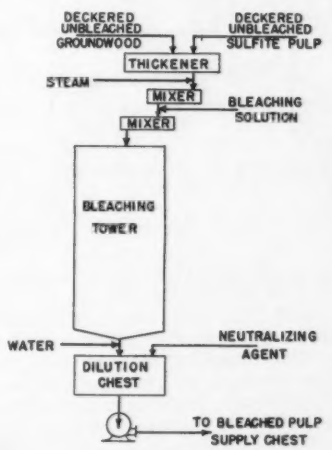


FIG. 16

MEDIUM CONSISTENCY (9-15%) CONTINUOUS BLEACHING PROCESS FOR MIXED GROUNDWOOD & SULFITE PULP

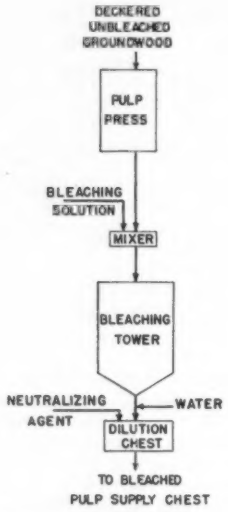


FIG. 18
HIGH CONSISTENCY (20-35%) BLEACHING PROCESS

Strength—The strength characteristics of groundwood do not appear to be improved or impaired by the bleaching treatment. However, data on paper strengths indicate a trend toward increased strength with the bleached pulp.

Formation—This increase in strength may be due to a more uniform formation on the paper machine, since it is apparent that the bleaching process has some defibering action to produce a more uniform and better separated pulp. The finished paper has a smoother and more velvety feel and does not show the harshness frequently associated with unbleached groundwood sheets. It is more homogeneous and is finer in texture than corresponding grades of paper made with unbleached groundwood.

Cleanliness—Fiber bundles and dirt specks present in unbleached groundwood are softened and largely disappear in the bleaching treatment. Slime formation is eliminated from the bleaching system and dirt does not develop from this source.

Absorbency—The water absorbency of groundwood and of groundwood papers is improved by peroxide bleaching; this improvement in absorbency is retained on storage. Also, bleached groundwood does not affect absorbency as much as unbleached groundwood in papers treated for wet strength. The absorbency toward oil is high and rapid.

Printing Properties—Groundwood papers have desirbale printing characteristics. They have an inherent resilience or compressibility which permits them to be printed uniformly with less pressure. Unbleached groundwood prints well but necessitates a sacrifice in the appearance of the paper; peroxide bleaching improves both appearance and printability.

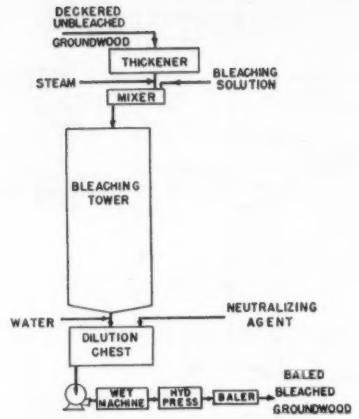


FIG. 19
MEDIUM CONSISTENCY BLEACHING PROCESS
FOR
PULP MILLS

XI. Economic Considerations

Conservation of Pulpwood—In the production of groundwood the fiber yields are high (95% or higher) and the weight loss in the peroxide bleaching process is low (1% or less). Use of groundwood in paper manufacture, therefore provides a means for converting pulpwood into paper with a maximum fiber recovery.

The loss of fiber in the production of chemical pulps varies somewhat with the nature of the processing; an

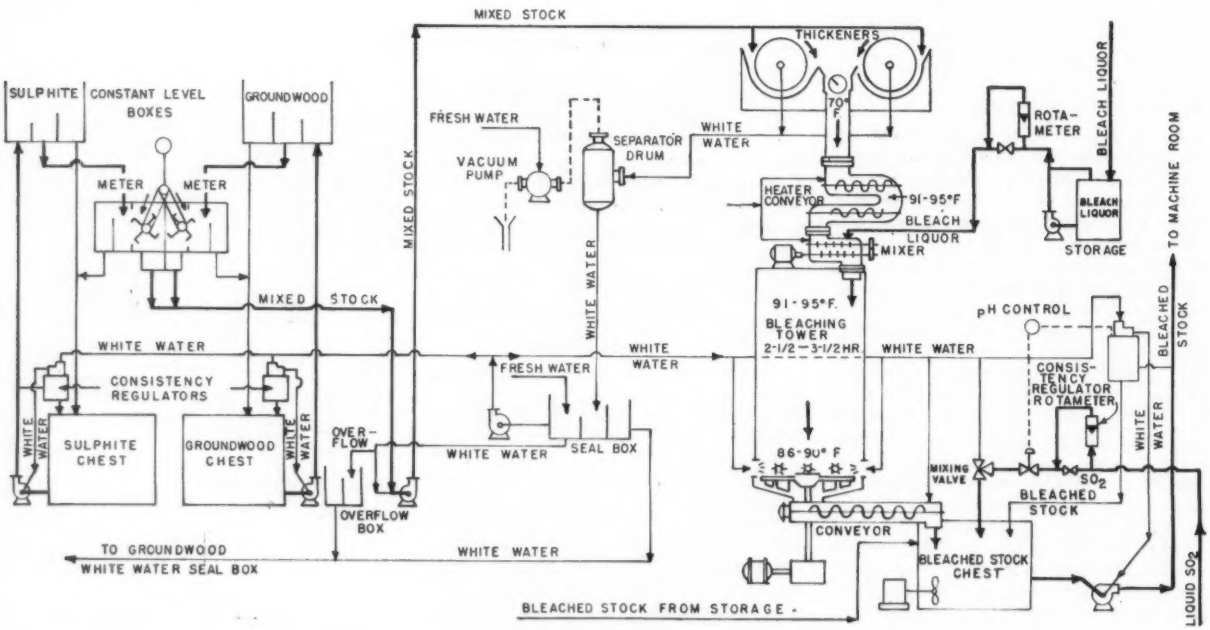


FIGURE 17
BLEACHING MIXTURES
OF GROUNDWOOD AND SULPHITE PULP
WITH
"SOLOZONE" SODIUM PEROXIDE

additional loss is incurred in bleaching. In the conversion of pulpwood into chemical fiber the yields are in the range of 45 to 55% for unbleached pulps and somewhat below this figure for bleached pulps.

In the production of fiber from pulpwood for paper manufacture, the yields of groundwood are approximately double the fiber yields obtained in the chemical pulping processes. Bleaching the groundwood with peroxide makes it possible to utilize higher percentages of this high yield pulp in the paper furnish.

Waste Disposal—Disposal of waste products constitutes a major problem in the production of sulfite pulps; the liquor from the digesters contains about half of the weight of the pulpwood. Waste disposal is a negligible problem in groundwood production.

Savings in Paper Manufacture— Substantial savings in fiber cost are realized by using bleached groundwood for producing papers in which brightness, bulk, opacity, absorbency and printing properties are important and in which high strength and a long useful life are not essential. The principal savings are based on: (a) lower cost of fiber, and (b) improved opacity obtained in the same weight sheet or same opacity obtained in a lighter weight sheet. Savings of 10 to 20% in fiber costs are obtainable in the production of many kinds of papers; in some types of furnishes the savings are as high as 40% of the total fiber cost.

XII. Recovery of Waste Papers with a High Groundwood Content

A process closely allied to peroxide bleaching of groundwood is the peroxide process for the recovery of waste papers with a high groundwood content.

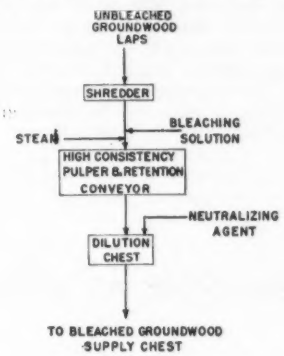


FIG. 21.
HIGH CONSISTENCY(20-25%)BLEACHING PROCESS FOR NON-INTEGRATED PAPER MILLS

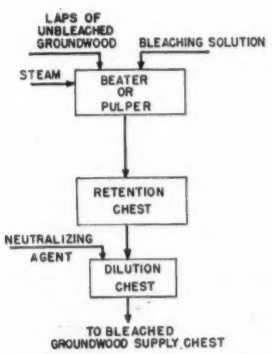


FIG. 20
LOW CONSISTENCY(4-6 %)BATCH BLEACHING PROCESS FOR NON-INTEGRATED PAPER MILLS

U. S. consumption of paper has risen from 100 pounds per person in 1917 to 331 pounds in 1949. Accompanying this growing demand for paper products, the U. S. supply of pulpwood has been diminishing. A partial solution to this problem of supply and demand is being reached by a wider use of waste papers as a raw material for paper manufacture.

Consumption of waste papers increased from 4.5 million tons in 1939 to a rate of about 8 million tons in 1950. At the present time waste papers represent about 30% of the total fibrous raw materials used in U. S. paper production. Most of this waste paper is pulped and used in board manufacture, without deinking or bleaching. However, increasing quantities of waste papers are going into the manufacture of printing and allied grades, where deinking and bleaching are essential.

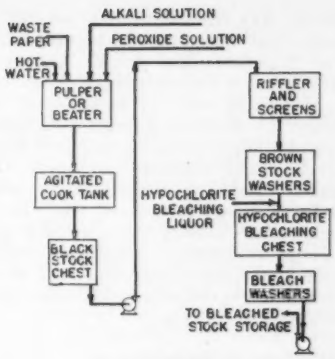


FIG. 22
WASTE PAPER RECOVERY PROCESS

Deinking of waste papers by the conventional alkaline pulping and cooking procedure is applicable to papers containing little or no groundwood. However, papers containing a substantial percentage of groundwood do not lend themselves to this treatment, in view of the browning which groundwood undergoes in an alkaline cook.

With the increasing use of groundwood, particularly bleached groundwood, in the production of printing and allied grades of paper, the supply of waste papers with little or no groundwood content has been decreasing to a point where a process for deinking and bleaching waste papers with a high groundwood content is an urgent need.

From laboratory investigations and confirmatory mill trials carried out several years ago, it became evident that such a process could be based on the use of peroxide in the operation.

Peroxide has the property of preventing the darkening of groundwood in the alkaline deinking cook and, in addition, it brightens the mechanical as well as the chemical fibers in the waste paper stock. Peroxide, furthermore, aids substantially in the pulping and deinking operation by attacking the various binding materials in the paper. It catalyzes and accelerates alkaline hydrolysis reactions such as (a) saponification of oils of the fatty acid glyceride type into glycerol and the sodium salt of the fatty acid, both of which are water soluble, (b) hydrolytic splitting of proteins, such as casein or glue, into water-soluble salts of amino acids, and (c) conversion of starch to a more readily water-soluble form.

Based on these combined properties, a peroxide process for the recovery of waste papers with a high groundwood

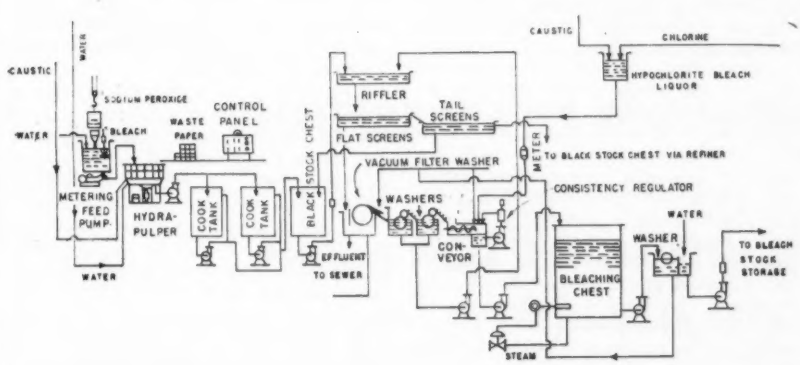


FIGURE 23

WASTE PAPER RECOVERY PROCESS

content has been put into successful commercial operation in several mills over the past few years. A typical installation is shown diagrammatically in *Figure 22* and in more detail in *Figure 23*. In this process the waste paper is pulped in a hot alkaline solution to which peroxide is added. The pulped stock is cooked with good mechanical agitation and the black stock, after passing over rifflers and screens, is given a thorough wash. After hypochlorite bleaching, the stock is washed and delivered to the bleached stock storage chest.

XIII. Peroxide Bleaching of Chemical Pulps

Research and development work on peroxide bleaching of chemical pulps has been proceeding with results that are most encouraging. From mill trials and commercial operations over the past two years, it is apparent that peroxides will prove useful in processes for bleaching both sulfite and kraft pulps.

XIV. Acknowledgment

I have enjoyed spending these two hours with you and in closing I want to say for myself and for my associates in du Pont, that it has been a pleasure indeed to have a hand in these developments in the pulp and paper industry. We want to express our sincere thanks again to the many chemists, engineers, equipment specialists, production supervisors, mill managers and executives in this industry for their kind and wholehearted cooperation.

PART III

CHEMIST AND CHEMICAL ENGINEER AT WORK

After spending two periods with you in the classroom this morning, in discussions that were rather technical in nature, I would like to take the opportunity this evening of talking with you about yourselves.

You young men, now in school in this splendid environment, are taking the first step in training yourselves for your chosen profession—chemistry and chemical engineering. You are in a fortunate group — fortunate because you can look forward to a life of achievement in a field where "better things for better living" are daily commonplaces and where the overall progress has been almost miraculous.

In the forty odd years since I was a freshman in college, the science of chemistry and the chemical indtustries have grown with leaps and bounds—they are destined to continue growing at an accelerating rate—with fundamental research pointing the way and industry bringing the fruits of research to bear on our ever improving American stadard of living. The progress made during these forty years, through teamwork between chemistry and engineering, is truly an outstanding factor in the economic gdowth of our nation.

Chemistry has provided new materials, new metals and alloys, new synthetic plastics and resins and a host of new chemicals which industry has made available for myriads of new uses. To cite just a few random examples:-

In the home the ice box has ben replaced by a refrigerator and a deep freeze unit. Our nutrition and health have been improved by items such as vitamins and penicillin. We have pyrex building blocks and pyrex dishes for cooking our meals. Our wardrobes have been enhanced by new fibers and fabrics. Radio and television are contributing to our enjoyment and to our knowledge of world affairs.

Our modern automobile has tires and tubes with a tenfold increase in miles of practically trouble-free operation. It has "leaded" gasoline in higher compression engines; it has a battery for starter and lights to replace the crank and the acetylene lamps; it has safety glass for windows and windshields.

In steam power plants, better alloys as structural materials have made it possible to increase pressures about tenfold, with efficiencies raised from about 75% to about 85%. Diesel engines, gas turbines and jet propulsion are in operation, and powering with atomic energy appears to be in the offing. Airplanes have become an important factor in transportation.

During the coming 3-5 decades, you efforts, combined with the efforts of the thousands of other young men now starting their training in chemistry in the colleges and universities throughout our land, will result in even greater progress. As a baseball team needs pitchers and catchers, infields and outfielders—and as a football team needs men on the line and in the backfield—and as the baseball nine and the football eleven need a captain and a coach—so the American Chemical Team needs a variety of talents and abilities to create, manufacture and distribute the chemical products which contribute to "Better Things for Better Living." Now is the time to ask yourself the question:—"What position on the American Chemical Team do I want to play?"

The young chemist and the young chemical engineer when his school days are over—when he has finished getting a birds-eye view of what scientists and engineers before him have learned and published, can set his course in one of a number of directions.

1. Educational institutions, such as the University of Maine, Colby, Bowdoin and Bates in your own state or the numerous colleges and universities in other localities.

2. Government laboratories, vast in proportions and dealing with practically all phases of our country's endeavors. In the field of pulp and paper the U. S. Forest Products Laboratory in Madison is illustrative.

3. Endowed or privately supported research instiutions, such as Mellon in Pittsburgh and Battelle in Columbus.

4. Consulting laboratories, such as A. D. Little and Foster D. Snell.

5. Industrial organizations, such as du Pont, Carbide & Carbon, Monsanto, Dow, and Eastman.

It may be of interest to you to know that in a survey of the chemical profession, made by Steelman in 1947, 48% indicated a preference for university teaching and research, 31% for the industrial field and 11% for government laboratories. I want to say that I enjoyed my six years of university teaching and research, for its freedom in the choice of work—for the inspiring contacts with eager, youthful minds—and for the grand environment of a college campus. Your own teachers are in the best position to amplify this picture and to advise you in this field.

Assuming that you have decided on a career in the chemical industry, you will want to consider the factors which have a bearing on the choice of a position. Among these we might include the following:-

1. Opportunity for advancement.

2. Security of employment.

3. Size, location, progressiveness, stability and financial standing of the company.

4. Policies of the the company on employee relations.

Different people will vary in the emphasis they place on these items and many new employees are influenced to join a particular firm through friends and associates.

In the field of industrial chemistry the young university graduate, including bachelors, masters and doctors, will go to work in one of various lines. At this stage the following abilities should be cultivated and improved:-

1. The ability to express thoughts clearly in speech and in writing. The maximum value will come from a technical job well done only if the results are expressed clearly in roundtable discussions and conferences, as well as in written status reports.

2. The ability to work well as a member of a team. Industry problems, without exception, require the coordinated efforts of a group of men.

All technical achievements in industry require good teamwork. Each member of the team contributes his share to the success of the team, giving due consideration to the abilities, the opinions and the personalities of the other members of his team. And, incidentally, the members of a well-functioning team learn a lot from each other.

The types of work in which scientists and engineers are engaged in the chemical industries may be classified broadly as follows:—(1) research, (2) development, (3) production, and (3) sales.

Research includes (a) laboratory exploration of improvements in present manufacturing processes, e.g., cheaper or better or more readily available raw materials, lower processing costs, better quality product; (b) finding new products which can be produced and sold at a profit in a ready market; (c) developing improved methods for applying existing chemical products in the consuming industries; and (d) exploring new fields of application for existing products. The conception of an idea in the research laboratory is merely a starting point in industry. Laboratory findings must be demonstrated in small scale operations by men familiar with structural materials, with chemical equipment and with sound engineering principles. In this development stage a more realistic consideration is given to the costs and economics of the process under study. When the results of the laboratory studies and the pilot plant evaluations indicate with reasonable assurance that a process can be operated to advantage, both the research group and the development group assist the engineering group in planning the layout and construction of the commercial plant. Operation of the plant is in the hands of the production group. This group is concerned chiefly with turning out each day the maximum quantity of product at a minimum cost, with due consideration of product quality and employees' welfare. Marketing the products of a chemical plant requires a sales group, whose activities include direct selling, advertising, sales development and market studies.

Now, assuming that you are planning to cast your lot with industry, you may be saying to yourself:—"I would like the research chemist's freedom of exploring my new ideas," or "I would prefer to do research on a larger scale in the pilot plant or in semiworks on partially proven ideas," or "I would prefer the job of keeping the wheels turning and the men happy in production," or "the life of a salesman will give my extrovert nature the opportunity of expressing itself." In response to these thoughts I would like to say that many of the best research men have taken a turn at development, production, and sales; also, many of the outstanding men in development have had experience in research, production, and sales; furthermore, many of the best production men have worked in research, development, and sales; and many of the best salesmen for chemical products have stewed and brewed in the research laboratory, have swung a pipe wrench in the pilot plant, and have sweated to get out the production.

So the young technical man during his early years in the chemical industries is more than likely to find himself accumulating experience in research, development, production, and sales. If this well-rounded experience does not come your way without asking for it—it is worth the asking.

Now, if during the period of experience-gathering in research, development, production, and sales the technical man shows that he has technical ability, that he expresses himself well, that he can inspire a team, that he exercises unusually good judgment, he may be drawn into management. This trend toward drawing on the technical men in an organization for top management is comparatively new, but has grown to a striking degree over the past 10-15 years. To cite a few instances in the pulp and paper industry—Howard Morgan, who a few years ago was Research Supervisor at the Institute of Paper Chemistry, is now Manager of the Pulp Division of Weyerhaeuser; Ward Harrison recently rose from a technical background to the Vice-Presidency of the Riegel Paper Corporation; Lyman Beeman, a graduate in Chemistry, is President of Finch, Pruyn; Fred Goodwill, formerly Technical Director for St. Regis, is Manager of the St. Regis mill at Kalamazoo; Russell Shearer, a graduate in pulp and paper chemistry, is managing a group of mills for Howard Smith; Allan Abrams, a graduate in chemical engineering, is now Executive Vice-President of Marathon; H. P. Bailey, a graduate in chemistry from the University of Maine, is now Manager of the International Paper mill at Niagara Falls; Forest Grainerd has advanced from Technical Director to Vice-President and General Manager of pulp mills for Scott—and coming closer to home, the competent, young President of du Pont is a graduate in chemical engineering, who rose from his first job in the chemical laboratory to give outstanding leadership to our company.

May I in conclusion leave the following thought with you:—

1. Learn all you can while you are in school. In addition to a good technical background you will find two things basically important:—(a) the ability to express yourself well, both in speech and in writing, and (b) the ability to cooperate well in teamwork with your associates and to inspire the members of your team.

2. Sell yourself thoroughly in the selection of your field of endeavor and start your first job with enthusiasm.

3. Consider the first ten years or so at work as a further training period. Continue to improve your technical ability, your ability to express yourself, your ability to cooperate in teamwork and to inspire your teammates, and your ability to exercise good judgment. Whether eventually you expect to be in research, in development, in production or in sales, you will do a better job in any of these lines if you take a turn at each of them during your early years.

4. Remember that, in the chemical profession, jobs with greater opportunities are constantly looking for men who can handle them. For the competent and capable technical man who can express himself well, who can inspire good teamwork, and who exercises good judgment, there is room at the top. So set your sights high!

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Peroxide Bleaching

Robert L. McEwen[1]

Graduated from Princeton University in 1935, having majored in Chemistry. Following graduation, he joined the Research Department of the Buffalo Electro-Chemical Co., Inc., having specialized in bleaching research and development as related to the textile industry. Since 1944 he has been in charge of Becco's Pulp and Paper Research and Development program, which is his present position. He has authored and coauthored numerous articles and patents on bleaching using peroxygen compounds.

Introduction

The utilization of peroxide by the pulp and paper industry is a relatively recent development. Very little peroxide was produced in this country prior to the building of two hydrogen peroxide plants on the Niagara Frontier about 1926. Prior to this, some hydrogen peroxide and sodium peroxide was imported from Europe, and a small amount of hydrogen peroxide was prepared in the United States from barium peroxide. Impetus to the production of hydrogen peroxide in this country was given by bleaching developments in the textile industry. Today, about 80 percent to 90 percent of all the cotton, either colored or white, is bleached with hydrogen peroxide.

Chlorine has been the primary pulp-bleaching agent for many years, and probably will continue to be the main purification and bleaching agent for chemical pulps. In the late 1930's and early 1940's, major peroxide application and development studies were undertaken in order to make groundwood pulps more acceptable in printing and tissue furnishes. Since that time, considerable time and effort on the part of the mills and peroxide manufacturers has been given to studies of bleaching processes using peroxide for semi-chemicals, sulfites, krafts, and other pulps. The original motivation, in the case of groundwood, was saving wood, lowering furnish costs of papers, and making expanded use of groundwood's properties of softness, resilience, and bulk. Peroxide bleaching of groundwood was the answer, primarily for printing and tissue papers. At the present time, about 20 mills in the country are bleaching either groundwood, sulfite, or groundwood - sulfite mixtures, and extensive mill development studies are well advanced for the bleaching of semi-chemical, kraft, and soda pulps with peroxide.

Variables of Peroxide Bleaching Process

In peroxide bleaching processes, the many variables are qualitatively similar for all pulp types, but vary quantitatively. The primary differences relate to the density at which a mill may operate, the available equipment, the pulp type, its previous treatment, and the brightness desired. Minor variations relate to temperature, alkalinity, time, and peroxide buffering activity.

These variables may conveniently be segregated into two categories, chemical and physical. It should be pointed out that one cannot consider them separately due to their close interdependence. However, there are broad generalizations which can be discussed:

A. Chemical Variables

First let us consider the chemical variables: *Hydrogen Peroxide* is a slightly acidic material which ionizes, it is commonly believed, as follows:

$$H_2O_2 \rightarrow H^+ + HO_2^- \quad (1)$$

It is generally accepted that the HO_2^- ion is the active bleaching agent. In a peroxide bleaching system, alkali is usually needed to effect decolorization of the naturally occurring coloring material. The alkali ionizes in the following form:

$$NaOH \rightarrow Na^+ + OH^- \quad (2)$$

The hydroxyl ion reacts with the hydrogen ion to form water, thereby displacing reaction (1) to the right. This applies equally well to sodium peroxide which, in essence, reacts with water as follows:

$$Na_2O_2 + 2\ H_2O = 2\ NaOH + H_2O_2 \quad (3)$$

The hydrogen peroxide produced by this reaction further reacts as in equation (1) above.

Heavy metal catalysts in a peroxide system are to be avoided due to the fact that catalytic decomposition can take place according to the reaction:

$$2\ H_2O_2 \rightarrow 2\ H_2O + O_2\uparrow \quad (4)$$

These decomposition catalysts are generally iron, copper, manganese, and some types of enzymes. Equation (1) above is the reaction desired and equation (4) must be suppressed.

A plot of brightness vs. percent peroxide is non-linear, as may be seen from *Figure 1.* This is typical of practically all pulp types when bleached with peroxide.

Alkalis are used in conjunction with peroxides in order to effect bleaching. Generally, the starting pH of a peroxide system will be in the range of 10-11, with the pH dropping during the bleaching cycle, the degree and rate depending on the cellulose purity, temperature, etc. The two commonly usel alkalis are caustic soda and liquid silicate of soda.

The amount of caustic used depends upon the bleaching temperature, the density, the amount of peroxide, and the pulp type. As density and temperature are raised, less caustic is desired; and as the purity of the pulp increases, the amount of caustic should increase.

Silicate of soda is not only a source of alkali, but is primarily used as a buffering agent for pH control. It

Figure 1—Relationship of % H_2O_2 to brightness

Northwest Pedigreed Papers

PRINTING PAPERS

Northwest Bond · Northwest Ledger · Northwest Mimeo Bond · Northwest Duplicator
Northwest Index Bristol · Northwest Postcard · Klo-Kay Book · Mountie Book
Klo-Kay E. F. Label · Klo-Kay E. F. Litho Label · Mountie E. F. Label · Mountie E. F. Litho Label
Mountie Offset · Mountie Text · Carlton Bond · Carlton Ledger
Carlton Mimeograph · Carlton Duplicator · North Star Writing · Non-Fading Poster · Map Bond

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serves also as a means of passivating heavy metal decomposition catalysts which occur naturally with the pulp, or which are introduced along with the water or the pulp handling equipment. Silicate is increased as pulp purity decreases; it is increased as bleaching temperature or caustic soda is increased. For groundwood, 4-6 percent silicate is used; for chemical pulps, usually 0.50-3.0 percent is used, depending on density and process conditions.

Water is another variable which must be considered in any peroxide bleaching process, as iron, organic coloring matter, etc., will depress pulp brightness. In addition, industrial wastes containing reducing agents will have a peroxide demand. Clear water of low iron content is highly desirable. Iron pickup from pulp handling equipment should be kept at a minimum.

The wood species, wood quality, and pulp type are also important considerations. Generally, the peroxide bleachability of wood species will fall into the following order of decreasing bleach response: Poplar, birch, spruce, Eastern softwoods, pines, hemlocks, and Douglas fir. Solid wood, of low heartwood content and processed in a fresh condition, will generally give the highest initial brightness and bleach responses. *Single stage* peroxide bleaching will, in general, establish the following order of decreasing bleach response: Sulfite, semi-bleached kraft, groundwood, chemiground, semichemical, unbleached kraft and soda.

Most peroxide processes require neutralizing agents which are generally SO_2 or its derivatives, or mineral acids. The SO_2 derivatives are particularly desirable for use with peroxide-bleached pulps which are furnished with unbleached sulfite, as traces of peroxide (similar to hypochlorite) will sometimes redden the sulfite fraction, thereby depressing furnish brightness.

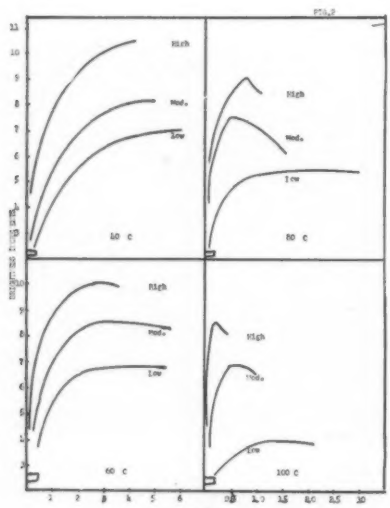

Figure 2—Relationship of Density, Time, and Temperature. (Groundwood bleached with 1.0% H_2O_2; 50% Caustic Soda lowered as Density and/or Temperature Increased)

B. Physical Variables

The primary physical variables are time, temperature, and density *(Figure 2)*. These three are all closely interdependent. The following broad generalizations may be mentioned:

Bleaching time decreases as density, temperature, and caustic alkalinity are increased. Brightness increases (with in limits) as temperature or alkalinity increased. Brightness increases (with-is increased. We feel the maximum safe operating temperature for groundwood pulp to be 115° F, but purified chemical pulps may advantageously use temperatures up to 130-160° F. Total alkalinity maximums exist for impure pulps such as groundwood, otherwise reversion of brightness occurs; purified chemical pulp types may tolerate excessive alkalinities.

The most important variable of a peroxide process is bleaching density. As density increases, high brightness is obtained per unit of peroxide and at the same time the bleaching rate increases. Pilot studies on groundwood have shown savings in chemicals at the same final brightness as density is increased from 5 percent, through 12 percent, to 35 percent density (See *Figure 3*). Thorough mixing of pulp and chemicals at densities above about 10 percent is extremely important, particularly in the range of 30-40 percent density.

C. Interdependence of the Variables

The interdependence of the variables, time, temperature, density, and chemical formula should be considered in relation to each pulp type, and the optimum set of conditions for obtaining highest brightness at lowest chemical cost may be determined empirically.

The amount of peroxide to be used is set by the brightness desired, the initial brightness, the pulp type and quality, as well as bleaching density. Generally, the economic level of peroxide will be about 1.0-2.0 percent H_2O_2 (50%) for groundwood, semichemical, and sulfite pulps bleached in a single stage; whereas 0.25-0.50 percent H_2O_2 (50%) is the range of economic interest in superbleaching applications for kraft, sulfite, and soda pulps.

The amount of silicate will depend on the pulp type and quality, time, and temperature conditions. Ordinarily, impure pulps are bleached with 4.0-5.0 percent silicate of soda (41° Be), whereas the purified pulps will use from about 0.5-3.0 percent depending on H_2O_2 level and process. The amount of caustic alkali required will depend upon the pulp, the amount of peroxide, and the bleaching density and temperature. Groundwood requires about 1.0-1.2 percent caustic soda at low density, about 0.75 percent at 12 percent density, and generally no caustic at densities above about 20 percent, all considered at about the 1.7-2.0 percent H_2O_2 (50%) dosage level. Lower H_2O_2 levels require correspondingly less caustic soda.

The best procedure in investigating the variables of a process is to set first the maximum usable density, and then set the highest temperature permissable and the levels of silicate and peroxide percentage, for the pulp under study. With these variables set, it is best to determine the caustic alkalinity empirically. Procedures for laboratory bleaching are available.

Peroxide Bleaching Processes

There are many peroxide bleaching processes available, selection of one being dependent upon pulp type, the available equipment, and the investment limitations. Most peroxide processes are single stage, as in the case of groundwood, semichemical, and sulfite; others use a peroxide stage generally following a hypochlorite oxidation stage, as in the case of semichemical, sulfite, kraft, and soda. In multi-stage systems, peroxide is best applied as a last stage.

All peroxide stages, *per se*, consist of thickening to the maximum possible density, blending pulp and chemicals, retaining the pulp in order to permit bleaching, and finally neutralizing the

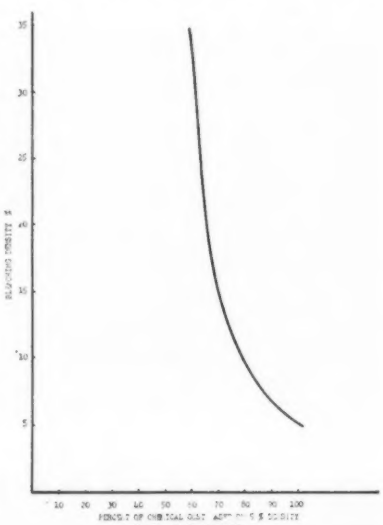

Figure 3—Effect of Groundwood Bleaching Density on Chemical Cost

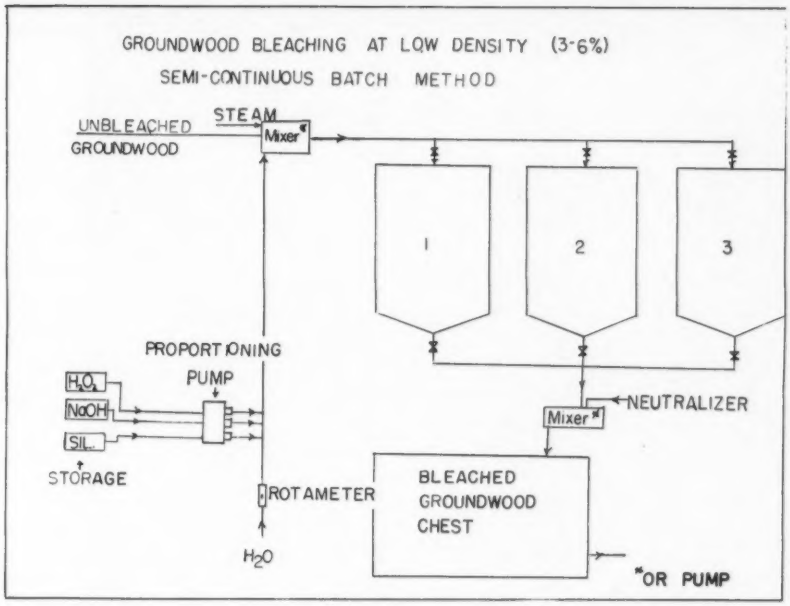

Figure 4

residual alkalinity. As in the case of groundwood, washing of peroxide-bleached pulp is often unnecessary.

In order to avoid confusion, arbitrary classification of peroxide bleaching systems is made according to bleaching density:

Low density—3-6 percent consistency

Moderate density—10-15 percent consistency

High density—Above 20 percent consistency

This classification would apply to any batch, semi-continuous, or continuous system.

A. Low Density Systems—3-6 Per Cent Consistency

Low density processes are sometimes used because of equipment availability, small pulp tonnages, and low investment *(Figure 4)*. At low density the bleaching rate is slower, the brightness increment is less, and the retention equipment must be of greater capacity than with moderate or high density systems. They may be batch or continuous. Chemicals and deckered pulp are blended in a mixer or pump and steam is applied to raise the temperature to about 90-115° F for groundwood, and to 130-160° F for chemical pulps. The pulp is thereafter retained for about three to six hours and neutralized. Not many mills are using low density systems, nor are many planning to use them, due to the comparative inefficiency of bleaching in the presence of so much dilution water.

B. Moderate Density Systems—10-15 Per Cent Consistency

Moderate density systems require less bleaching time and lower caustic alkalinity formulae than low density systems. Higher brightnesses percent of peroxide are obtained. *Figure 5* schematically shows a moderate density continuous tower system as used for both groundwoods and chemical pulps. The stock is regulated, metered, and thickened on a vacuum cylinder. After discharge it is heated, blended with peroxide chemicals, and dropped to a retention tower. Retention times will vary from 1½ to 3 hours at 90-115° F for groundwood and from 1½ to 24 hours at 70-160° F for chemical pulps depending upon initial brightness, brightness level desired, pulp purity, bleaching temperature, and process used. From the tower, it is discharged, neutralized, and sent to the bleached-stock storage chest for furnish preparation. Most recent improvements in moderate density processes have related to improved control of the operation through instrumentation. In addition, towers having water-jet discharge systems have come into use in the past two years.

C. High Density Systems — Above 20 Per Cent Consistency

Our research and mill development efforts in the past several years have been in the perfecting of high density processes. Motivation has been to increase bleaching efficiency and, in continuous systems, to shorten retention times thereby reducing space requirements, etc. Since 1948, several high density processes have come into commercial use. Some systems have been designed as well for low production pulp mills.

Figure 6 schematically shows a continuous high density tower system for handling pulp in crumb form. Deckered stock, preferably at a known rate, is dewatered to about 30-40 percent, in screw presses, after which chemicals are blended in a refiner-type mixer. Thereafter, pulp is delivered to a flared retention tower wherein bleaching is effected. Groundwoods generally required retention times of 1 to 2 hours to effect maximum brightness at temperatures of 110° F, whereas chemical pulps require retention times of 1 to 3 hours at temperatures up to about 160° F. After retention, the pulp is discharged from the tower, diluted and neutralized prior to being sent to the bleached-stock storage chest.

A variation of the above continuous tower system for crumbs is the semi-continuous steep bleaching process *(Figure 7)* in which the high density pulp, after blending with chemicals as above, is discharged to a freight car, truck trailer or to bins or chests for

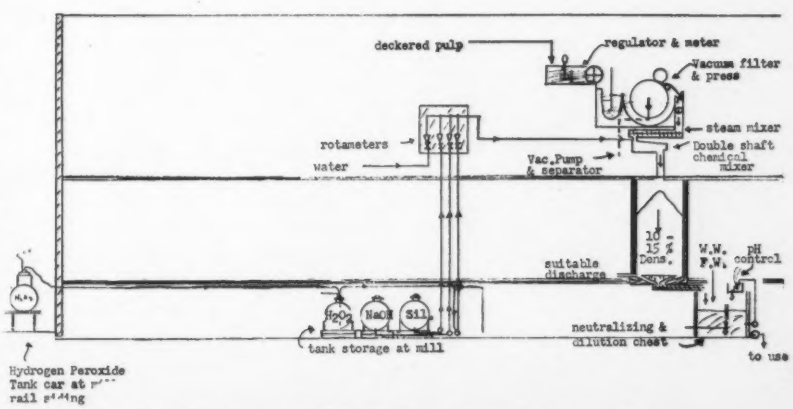

Figure 5—Moderate Density Continuous Peroxide Bleaching System

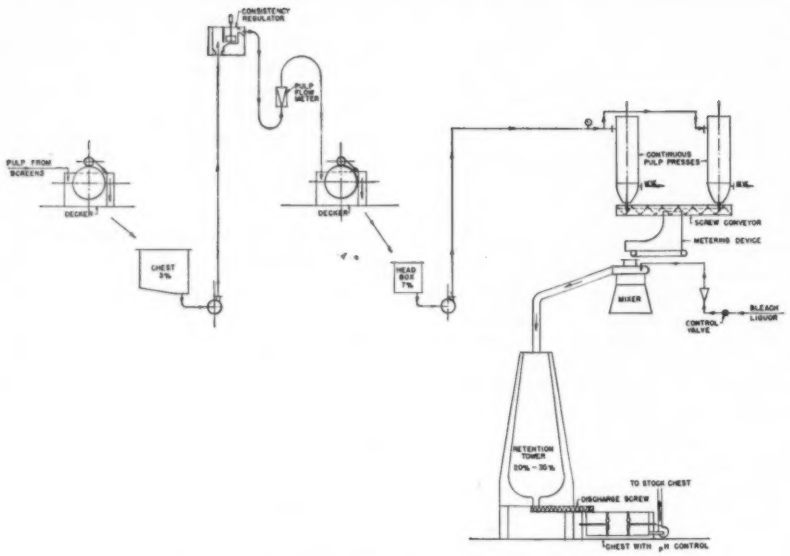

Figure 6—Continuous High Density Bleaching System

storage or shipment at ambient temperatures for periods from one up to seven days, or up to several weeks if desired. Groundwood requires no post neutralization. With the steep process, bleaching is effected at a slower rate, but chemical economy is the best of any system known.

The steeping process also permits the bleaching of continuous pulp sheets as prepared on either a kamyr, Rogers, or on a fourdrinier or cylinder wet end. Physically, the sheets must be strong enough to be self-sustaining and must be separated from any carrying felt at the point of chemical dosage, inasmuch as total chemicals applied must be retained for optimum chemical efficiency. *Figure 8* shows the process using a kamyr wet machine. In this case, the moist sheets at about 30-50 percent solids are either cut or wound into rolls and allowed to stand at existing temperatures either in storage or during transit. Bleaching efficiencies here again are of the highest and pulp quality is excellent.

A variation of the above high density system, presently under extensive

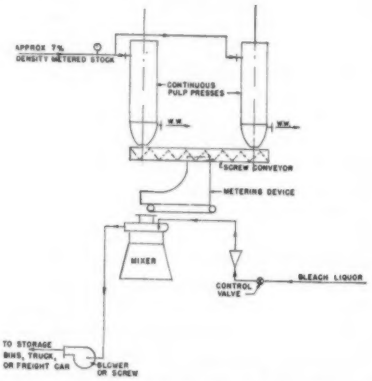

Figure 7—High Density Steep Bleaching of Pulp Crumbs

mill study, consists of impregnating pulp or paper webs with special hydrogen peroxide liquors prior to drying. The system is called Drier Steep Bleaching or Machine Bleaching and makes possible the close control of finished pulp or paper brightness either in the moderate brightness or superbleaching ranges. Our research and development efforts at the mill level are progressing and at this time it is indicated that the process will prove to be of considerable merit.

D. Deinking Processes

As this subject is well covered in a symposium presented in Paper Industry (Pap. Ind. *31*, No. 3 330:342, June 1949), little need be said here. Mention should be made, however, of the fact that peroxides may be advantageously added to the alkaline repulping step in waste paper recovery. The peroxide will help maintain the brightness of any groundwood pulp fraction occurring in the waste paper and will aid in the ink removal in subsequent washing operations.

Applications to Pulp Types

Peroxide bleaching of pulps not only increases the reflectivity of the pulp in question, but also softens fiber, bleaches most of the usual forms of dirt, and, if the process conditions are properly chosen, will result in other physical and chemical properties remaining unchanged. Let us consider, therefore, pulp types:

A. Groundwoods and Chemigroundwoods

As considered before, the brightness response will be dependent upon the wood species, condition, process density, and water conditions. Generally, 0.75-1.5 percent hydrogen peroxide (50%) is used along with 4.0-5.0 percent silicate of soda and 0.0-1.0 percent caustic soda, dependent upon density, time, etc. Ordinarily, one expects 7 to 14 brightness points rise using 1.5 percent hydrogen peroxide (50%), the higher figure being possible with easy-bleaching species at high density. Yields are substantially 100 percent based on unbleached pulp.

Chemigroundwoods, prepared by the neutral sulfite procedure, respond to about the same degree as regular groundwood of the same species, although initial brightnesses are generally lower.

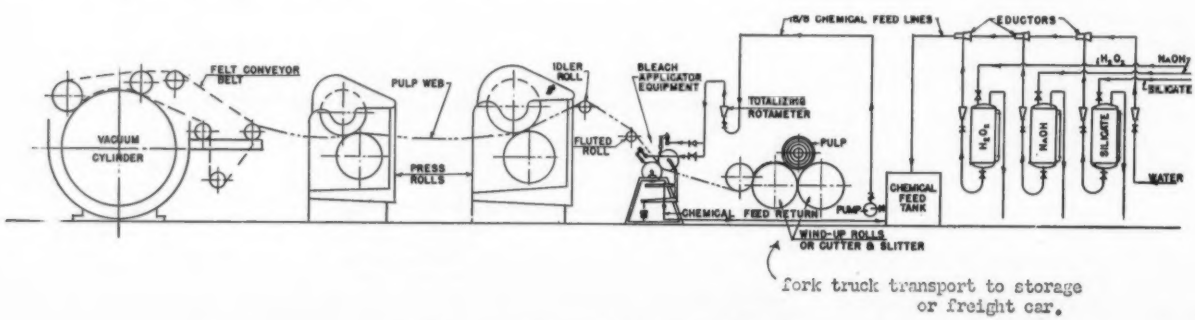

Figure 8—Steep Bleaching of Continuous Pulp Webs

B. Semichemicals

A single-stage moderate or high density peroxide process will, in many cases, elevate neutral sulfite semichemical aspen pulps to about the 70 G.E. brightness level. Aspen cold caustic soda semichemical pulp is bleached to the 70 brightness level (from 50), using 2.0 percent H_2O_2 (50% in a high density steep bleach process. Kraft or soda type semichemicals require at least a hypochlorite treatment preceding the peroxide stage. These multi-stage sequences would be a two-stage hypochlorite - peroxide sequence or a chlorination, extraction, hypochlorite - peroxide sequence. In this case, the peroxide stage will improve the color stability to heat and light. A single stage peroxide system will give bleached pulp yields in the order of 99+ percent for this stage.

C. Sulfites

The main role of peroxide systems for sulfite pulps is to superbleach without fiber degradation especially at high brightness levels (as, for instance, in a multi - stage system), simultaneously improving aging and color permanence.

Single - stage high - density peroxide processes applied to low permanganate number pulps, permit brightness elevation up to the 85 brightness level, at yields substantially 99 percent based on the unbleached pulp. The response is dependent upon the density used, the the amount of peroxide, and the unbleached pulp permanganate number. The physical properties are excellent, particularly with low - temperature, high-density systems.

Hydrogen peroxide is of great utility as well, when applied to sulfite following a hypochlorite, or following chlorine-caustic - hypochlorite systems. As a part of such sequences, the peroxide is applied preferably at moderate or high density. Here again, the peroxide acts as a superbleaching agent, resulting in pulps of improved color stability with physical properties substantially equivalent to those existing just prior to the peroxide stage.

Attention is called to an article which presents considerable data relating to these systems (*Tappi 34,* No. 5, 193-201, May 1951).

D. Krafts

Hydrogen peroxide in the kraft industry is used following a hypochlorite stage, or preferably following purification and hypochlorite stages in order to superbleach without degredation and/or to condition the bleached pulp so that heat, light, and storage stability are improved.

Ordinarily, from about 0.25-1.0 percent hydrogen peroxide (50%) is used in a final stage along with from 0.5-2.0 percent silicate of soda and about 0.0-0.5 percent caustic soda. Last stage peroxide treatments will very often superbleach to the 85-90 brightness level. Moderate density equipment may be used, whether the H_2O_2 stage is a replacement for a last stage hypochlorite or an additive steeping stage effected in 12 percent density storage towers, should they exist. High density systems found to be of commercial interest consist of either steep bleaching as a final stage, or a kamyr feltless wet machine, or moderate density superbleaching in the last stage or in the storage towers. In addition, considerable progress has been made in perfecting the pulp drier steeping process wherein krafts are superbleached on the driers. In this case, controlled hydrogen peroxide bleach liquors are applied after the kamyr or fourdrinier wet end and upon passage through either the driers, additional brightness is effected. Due to the presence of the peroxide in the bales while stored or shipped, a gain of 8 to 10 points in the high 80 brightness range is very often possible, compared with the standard baled pulp given the normal drying technique.

Another system is the use of peroxide in the alkaline extraction stage where ordinarily 0.5 percent hydrogen peroxide (50%) or equivalent, is added along with silicate of soda and the usual caustic alkali. This treatment eliminates the usual drop in brightness during the normal extraction stage, elevating the brightness somewhat, and thereby reducing the subsequent hypochlorite requirement for reaching a given brightness level.

Regardless of what last stage peroxide system is used, the last stage H_2O_2 bleach not only elevates the brightness, but contributes considerably improved heat, light and storage stability to the pulp. This fact is important because large tonnages of pulp are dried by heat for storage and/or shipment. Attention is again called to the reference, *Tappi 34,* No. 5, 193-201 (May 1951).

E. Soda Pulps

Soda pulps fall into the same category as kraft pulps with regard to peroxide bleachability, requiring at least a hypochlorite treatment prior to the peroxide stage. The value of a last-stage peroxide bleach relates to improved brightness and aging properties. Process information follows closely the pattern outlined under krafts immediately above.

F. Other Pulp Types

Extensive research and mill development studies relating to the bleaching of straw, bamboo, bagasse, flax, rag, and deinked pulps is in progress. The main advantage of the peroxide bleach is to produce high-yield pulps of reasonable brightness levels. The neutral sulfite type of cook for agricultural pulps better prepares the pulp for higher brightnesses. Alkaline - type cooks should be hypochlorite bleached prior to the peroxide stage. Flax pulps lend themselves extremely well to the high density steep superbleaching processes, improved physical properties being obtained at high brightness levels. High density peroxide processes are quite effective in the bleaching of previously deinked pulps.

Chemicals and Testing Procedures

Hydrogen Peroxide (H_2O_2 is a water-white liquid which is commercially obtainable generally in concentrations of 35 percent and 50 percent by weight. It is shipped and stored in high - purity aluminum tankage and drums. The usual procedure is to transfer the material from tank cars through aluminum piping to aluminum tank storage at the mill site. A blanket of air or a pump is used for this purpose, as well as to transfer from the storage tank to a measuring tank or proportioning pump, etc., at point of use.

Hydrogen Peroxide is not a systemic poison. Commercial hydrogen peroxide, as made and handled today, has excellent long-term stability. It is an entirely different product from the old time 3 percent drug-store variety. Contamination of the commercial H_2O_2 solution by dust, dirt, or decomposition catalysts such as copper, brass, iron, manganese, cobalt, etc., must be avoided.

Sodium Peroxide (Na_2O_2) is also used in bleaching pulps. It is a yellow solid containing approximately 20 percent active oxygen. It is hydroscopic and is therefore shipped in tightly closed 400 lb. drums. Evolution of oxygen and generation of heat will result if this material is allowed to pick up moisture from the air. As it is a solid, bleach liquor preparation is generally of the batch type.

Silicate of Soda ($Na_2O.SiO_2$), as used by the pulp industry, is generally about 40-41° Be grade containing approximately 8.9 percent Na_2O. This material is a source of alkali but more important is its function in stabilizing alkaline peroxide solutions so that the peroxide is more effective for bleaching and catalytic oxygen losses are kept to a minimum.

Caustic Soda and *Sulfuric Acid* are sometimes used. These are ordinary commercial grades, caustic soda generally being of the 50 percent liquid va-

riety and sulfuric acid being of the 66° Be grade.

Caustic soda generally, but not always, is used in conjunction with hydrogen peroxide, and sulfuric acid is used with sodium peroxide, in order to obtain the proper level of caustic soda alkalinity desired for a particular process. Numerous mills have used the *Mixed Peroxide System* which utilizes both hydrogen peroxide and sodium peroxide to make up the total active oxygen required in the bleach liquor. In this case, sodium peroxide is used to obtain the caustic alkalinity desired, and hydrogen peroxide to supply the additional active oxygen required. With this system, neither caustic soda nor sulfuric acid is used. At present chemical prices, the Mixed Peroxide System gives excellent overall economy.

Very often *magnesium sulfate* ($MgSO_4.7\ H_2O$), or epsom salts as it is commonly known, is used as an alkaline peroxide bleach liquor stabilizer in preparing batch solutions for storage periods of more than several hours. About four to five lbs. per 1000 gallons of bleach liquor is used.

Some specialty processes for pulp bleaching dictate the use of trisodium phosphate ($Na_3PO_4.12\ H_2O$) or tetra sodium pyro-phosphate ($Na_4P_2O_7$). Soda ash (Na_2CO_3) is generally not used in peroxide systems as a source of alkali.

Neutralizing agents are generally SO_2 or derivatives thereof. SO_2 is a liquid under pressure. It is shipped in cylinders or tank cars and is fed at a measured and controlled rate to the pulp slurry, generally after the peroxide bleach. Mineral acids may also be used for pH control at this point.

Procedures for testing the commercial chemicals used, as well as for testing chemicals on the pulp, are available, but are considered to be beyond the scope of this paper. Laboratory bleaching procedures for various densities are also available.

Bleach Liquor Preparation and Feeding Systems

Choice of either continuous or batch bleach liquor preparation systems is generally dictated by the local mills experience, as well as by the choice of all-liquid or both liquid and solid chemicals. The advantage of the continuous preparation and feeding system is that liquor is prepared as it is used, thereby eliminating possible active oxygen loss which may occur upon storage of alkaline peroxide solutions over extended periods of time. Many batch preparation systems are in use but there is a definite trend toward all-liquid continuous systems. *Figure 9* schematically shows batch and continuous systems.

Construction Materials

For pulp which contains peroxide chemicals, contact with equipment made of alkali-proof tile, stainless steel, and transite is preferred. In many cases, iron equipment which builds up a coating of silicate of soda through use, appears to be satisfactory. Preferred material of construction for concentrated bleach liquor preparation and transfer is stainless steel and/or tile, although in some cases clean iron or concrete tanks coated with silicate of soda are quite satisfactory.

As mentioned before, commercial hydrogen peroxide should be handled in high-purity aluminum, following the recommendations of the hydrogen peroxide manufacturers.

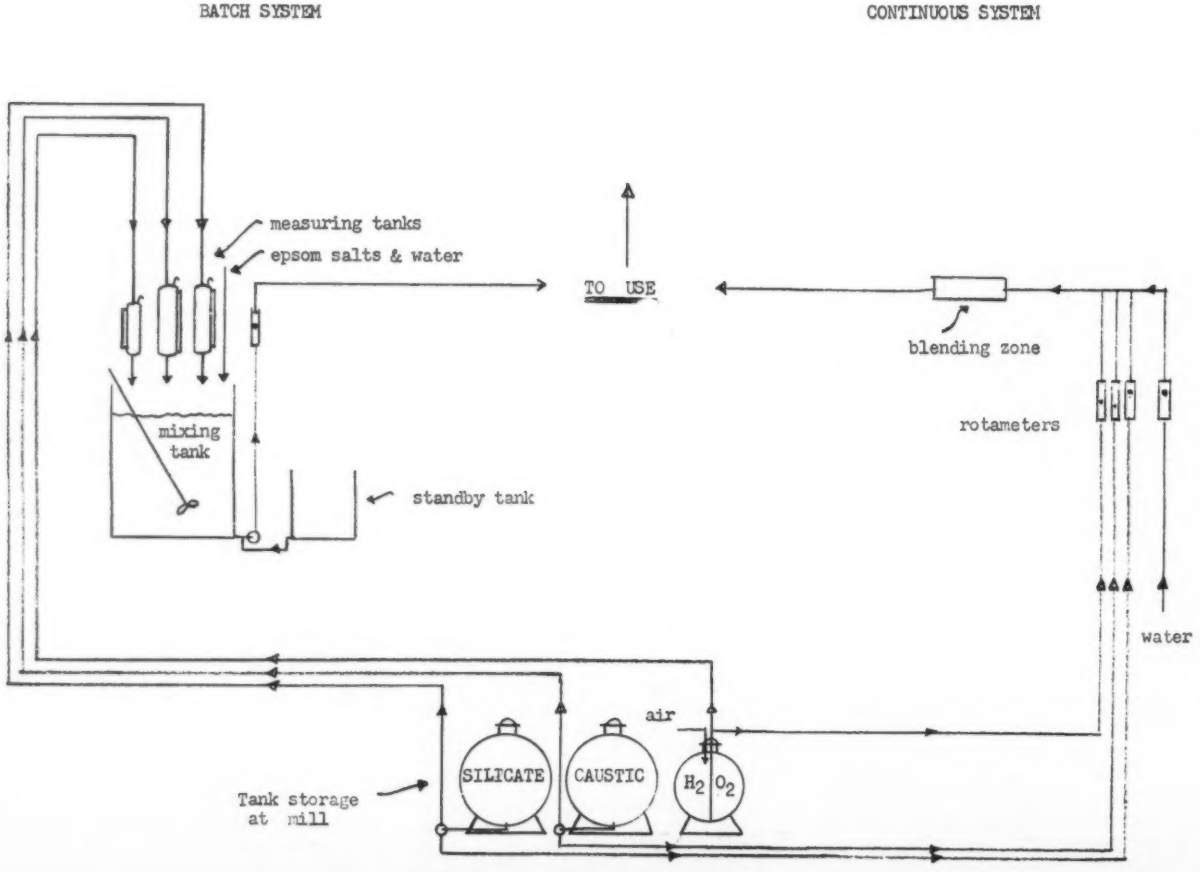

Figure 9—Chemical Preparation Systems

Conclusion

During the past 8 to 10 years, considerable progress has been made in bleaching pulps with hydrogen peroxide, and it is believed that its position in the industry is firmly established. This progress has been the result of excellent cooperation between many pulp and paper mills and peroxide manufacturers. It is believed that the continuation of this excellent cooperation will establish additional sound and very advantageous uses for hydrogen peroxide.

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Chlorine Bleaching

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Introduction

It is not my intention to discuss the chemical or physical properties of chlorine and its compounds. All of this material is available to you in text books that you already have. Instead I shall try to tell you about some of the things I have had to learn about the practical part of the handling of chlorine as used in present bleaching processes.

The first use of chlorine in quantity in pulp bleaching was in the form of chloride of lime or calcium hypochlorite. This was shipped to the mills in barrels in the familiar dry form. The available chlorine was about 35 percent by weight. A great deal of the early information on bleaching is expressed in percent of 35 percent bleaching powder.

Bleaching was started at Hollingsworth & Whitney Company in beaters using bleaching powder in 1913. We have no records to indicate how far they went up the brightness scale in those days. In fact we assume that the miracle itself was sufficient without worrying about brightness variations. Experiments were continued in beters until 1916 when the first Belmer was built. The Belmer is, of course, simply a large beater with a short screw for circulation. In 1918 the plant was enlarged to a two Belmer arrangement in a special building. About this time the first liquid chlorine was delivered to the mill.

The chlorine was shipped in one ton drums, 15 to a railroad car. A small number are still shipped this way. The drums were not insulated so the car had to be kept in a heated building in order to have enough pressure to empty the drums in cold weather. The chlorine was used with hydrated lime to make up the bleach liquor in solution or suspension.

In talking with the men who worked with chlorine in those days it appears that the physical ability to stand the gassing quickly determined who worked in this department. They had no gas masks or other protective equipment. During the First World War crude gas masks were developed, but at best they were poor protection. The men learned entirely by experience how to handle the liquid and stay alive.

Protective Equipment

This seems to be a good place to talk about protective equipment. The first gas masks had a canister provided with a mouth piece and nose clamp. They offered no eye protection, so when the gas was strong enough to make you cry you went by feel or got out until it cleared up.

The next masks, that came out about 1930, had a rubber face piece with head straps and exhalation valve that gave eye as well as breathing protection. In general as long as you cannot see chlorine in the air, you can get by with one of these masks.

In 1942 we first began to use the respirator. This is simply a rubber nose and mouth mask with small canisters and exhalation valve, but no eye protection. These are used for all minor gas leaks and many of our employees have them as emergency protection.

It was about this time that we first tried the ½ hour demand oxygen equipment. This consists of a rubber face piece connected to a breathing circuit that removes carbon dioxide and supplies oxygen from a cylinder. With this equipment a man has about ½ hour of complete breathing protection in any concentration of chlorine. At this point, however, we get into the problem of skin protection. At high concentrations, chlorine on wet skin under clothing can be very irritating.

The latest development in protective equipment is the Chemox breathing apparatus. This was set up for the Navy during the last war. It consists of a rubber face piece, connected to a breathing circuit that employs a single canister to remove carbon dioxide and generate oxygen. This gives protection for three quarters of an hour of intense physical effort or four to five hours of inactivity and, of course, works in any atmosphere.

Chlorine Handling

Dry chlorine is relatively non corrosive in either liquid or gaseous form at all normal temperatures. Drums and tank cars are made of steel. Valves are normally of bronze or steel with monel metal stems. Hastelloy "C" is used for valve trim. Steel pipe is used in all dry phases of the liquid and gas handling.

When chlorine is wet the problem becomes very complicated. The only satisfactory protection for large areas has been rubber covering. In high concentrations, however, chlorine attacks rubber. Hastelloy "C" at several dollars a pound is very good. The high silicon cast irons have been adapted to this use also. They are very brittle, however, and non machinable. Several plastic materials have been developed recently that show great promise. We are at present experimenting with a diaphragm material called Kel-F that seems to be completely resistant. U. S. Rubber Company has a plastic called Uscolite that seems to work well. Dupont's Teflon is completely resistant and serves very well as a packing material. Each application must be studied very carefully as so many properties are required to satisfy all of our needs. The stainless steels are useful for low concentrations of chlorine wanted but are apt to be rapidly attacked under some conditions.

Bleach Preparation

The apparatus used for making the bleach liquor has changed very little over the years. The chlorine was introduced through a crude injector into a circulating stream of lime water drawn from and returned to a tank. The circulation plus the injector effect would produce a slight vacuum on the chlorine pipe and drum when the cylinder was almost empty. We still use this principle and arrangement today to empty chlorine lines.

Our bleach liquor making equipment consists of a 10,000 gallon concrete tank with a circulating pump of 500 gallons per minute capacity with a chlorine injection tube in the downcomer on the pump discharge. The chlorine rate is about 2,000 pounds per

hour with the final liquor strength at 20 pounds per 100 gallons. The finished liquor is settled and the clear liquor decanted for use. The sludge remaining in the settling tank is diluted with water, and the decanted weak liquor used for makeup in the next batch. The second sludge is dumped. Recovery from the sludge amounts to about ten percent.

Multistage Bleaching

Up until 1935, bleaching at the Hollingsworth & Whitney Company can be described as single stage Belmer bleaching with calcium hypochlorite. The bleachability of the pulp was determined by dipping a portion of pulp in bleach liquor and estimating the bleach requirement from the color intensity and rate of change. The pulp was not washed after bleaching and color was matched from batch to batch. About 1934 the introduction of the G. E. Brightness Tester made it possible to set up color standards. Demands for uniform color and higher strength convinced H. & W. that they should install a recently developed two stage process using elemental chlorine in one stage, followed by a high density hypochlorite bleaching. After chlorination the pulp was neutralized before washing, since acid resistant washers were still in the development stage when the system was installed in 1935. We believed the operations in this new plant to be highly technical. The chlorine demand was determined by chemical test on the pulp. The five minute permanganate test which we began using at that time, and still use, is essentially the same as the present TAPPI standard test. It is possible to measure the total chlorine requirement for pulp bleaching to a given brightness or to determine the remaining bleach requirement at any point during the bleaching operation.

We began to receive chlorine in tank cars at about this time. The multi-unit chlorine car was also used with a manifold extending the length of the car, to which the drums were connected one at a time.

The single unit tank car presented a different problem. It was necessary to set up a system to supply dry air to the car as the chlorine had to be carried to a higher elevation for the chlorinator, and the car had to be emptied of its last 1500 to 2000 pounds by a stream of air. The piping problem was simplified, but the risk from leaks was multiplied, as the tank cars held from 16 to 30 tons when full, whereas on the multi unit only one drum had been connected at a time. The tank car has a ball valve in the chlorine discharge line that is supposed to rise and stop the flow when the rate exceeds about 7,000 pounds per hour. We had a break in our chlorine line several years ago but the ball valved failed to close. However, these balls will often rise and stop the flow when the valve is opened on an empty chlorine line.

The benefits realized from this two stage process were; more uniform brightness at lower chlorine consumption, with practically 100 percent retention of the unbleached strength; and lower steam consumption. However, these advantagse were obtained at the expense of cleanliness for as the process treated the fiber more gently it also treated the dirt more gently. We found that for an 80 brightness pulp we could furnish up to 80 percent of the total bleaching demand as chlorine with the remaining used as calcium hypochlorite. This pulp had the best strength characteristics and the poorest cleanliness. We finally settled down to a 65 percent chlorination and ran this way for a number of years.

A program of experimental bleaching was started at approximately the same time as the new plant. Of course, the first thing that had to be proven, was how close we could come experimentally to plant results. A series of experiments showed that our laboratory results retained about five percent more strength than plant bleaches.

Kraft Bleaching

We had been working all of this time on sulfite pulps. We had use, however, for bleached kraft pulps. The 1935 version of the bleach plant was provided with bypass piping so that it could be operated two, three, or four stage, etc., by multiplying the high density stages through transfer from one bleacher to the other over a washer. The daily capacity of the plant was dependent on the number of stages as follows: two stages, 50 tons; three stages, 35 tons; four stages, 25 tons.

About this time, the value of caustic extraction became generally known. Experience showed us that up to a certain point, our chlorine consumption was reduced one pound for each pound of caustic used. The caustic was used in a separate stage with one or two percent on the weight of the pulp at high density and 120 degrees Fahrenheit.

We ran a long series of experiments over a period of several years, following various bleaching developments and suggestions and using numerous types of kraft pulps.

Indications obtained from these experiments are shown in the following summary:

1. As the number of stages of bleaching is increased, the chlorine requirements decrease for any given brightness especially in the higher ranges.

2. Caustic extractions improve pulp quality and reduce chlorine consumption.

3. Very little apparent difference was found between pulp neutralized after chlorination and pulp washed in the acid state.

4. For each individual pulp, and each method of bleaching, there is an optimum percentage of chlorination.

An interesting variation was a vacuum chlorination method proposed at this time. This consisted of evacuation of the vessel containing the pulp, followed by chlorine injection to satisfy the vacuum and ultimately the chlorine demand of the pulp. We feel that this was an ideal chlorination method as the pulp produced was superior in every way. Mechanical difficulties prevented the large scale application of this method.

Bleached kraft pulps produced at this time normally did not exceed 75 brightness.

The rapid expansion of kraft pulping in the South in the early 1940's was followed by further developments and refinements in bleaching of the fibre from hard pines. Our plant at Mobile was equipped with a six stage continuous process that proved to be very efficient. The steps were chlorination (acid washed) caustic extraction, hypochlorite bleaching, caustic extraction, hypochlorite bleaching, acidification. Pulp can be produced in this way retaining almost 100 percent of the unbleached strength at 75 brightness.

We experimented with this pulp in our Waterville plant also. We used the following sequence. Chlorination (neutralized with lime) caustic extraction, hypochlorite bleaching with controlled pH, and finally acidification. Our plant was, of course, entirely batch and by very close control we could practically equal the performance of the six stage system at Mobile.

One phase of bleaching that has received too little attention, is the matter of chemical absorption by the fibre. The normal bleaching process calls for a wash after each stage. This consists of a dilution followed by displacement washing on the washer cylinder. This is naturally a very rapid process, while the chemical treatment normally lasts an hour at least. The chemicals penetrate the walls of the fibre but do not have time to come out in a normal washing cycle. We found, by experiment, that following chlorinations or caustic extractions, we could obtain higher brightness and strengths with lower chemical consumptions, by use of soaking stages following the first washing. A second wash was necessary also. Some mills have set up this type of process with good success.

Bleachability Tests

We have done a lot of work at various times with bleachability tests. As stated earlier, the five minute permanganate test has been in use at the mill for about 15 years. We have found this test to be very good on sulfite pulp made from spruce and fir. In other words the figures given by the test can be converted to equivalent chlorine and, by multiplication by the batch size, to pounds of chlorine per batch. However, there are times when the whole scale must be moved either up

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or down for no explainable reason. Poplar and hemlock pulps do not follow the same curve as spruce and fir. Our attempts to apply the permanganate test to kraft pulps were not very successful. It is general knowledge that in many kraft mills with bleach plants, this method is used as a routine test for bleachability. We concede that it may be possible to get comparable results under these specific conditions, but our problem was quite different, as we normally have five or six different varieties of kraft on hand for bleaching purposes. After strug gling with permanganate tests in various modifications, as well as methods using bleach liquor or chlorine, we finally gave up scientific methods entirely and now determine our bleachability during the process. As we found out with the vacuum chlorination, the best way to measure how much chlorine a pulp will take is to chlorinate it. The exhaustion test after a definite time interval provides the measure. In some continuous plants a special five minute chlorination tower is used for this purpose. In a batch plant you can chose your interval. The subsequent stages are furnished by trial in the same way.

Our 1935 bleach plant served well through World War II but it was felt at the close of the war that a larger bleaching system was needed. The 1935 plant was designed to allow the addition of more units. It was started with one chlorinator and two batch bleachers. The same chlorinator, now operated continuously instead of batch, a continuous high density caustic reactor, and five batch bleachers are now in operation. This arrangement is ideal for sulfite pulps and since it was first started the production has been tripled with the same operating crew. Kraft pulp could be handled at the same rate except that we have been unable to discover a furnishing method that will give us over 120 tons per day. We are also handicapped in our kraft bleaching in that, with so few stages, very exact control is required. We have not been able to get this in our two years of operating experience. It is our understanding that continuous plants get their results by a number of approximations. If the number of stages is great enough the results are very good. Most of our difficulties with the present plant have been in the continuous stages.

The Effect of Bleaching Variables

The bleaching process may be considered as an extension of the purification started by the cooking. Chlorination removes the bulk of the remaining lignin; caustic extraction reverses the pH and thus completes solution of the chlorinated lignins; Hypochlorite stages decolorize colored compounds. Pulp strength is affected as follows. Pulp after chlorination retains 100 percent of it's strength. The caustic extraction usually increases the strength. If the first two stages have been properly carried out, 80 to 83 brightness can be attained by hypochlorite bleaching, with practically 100 percent retention of the unbleached strength. Beating characteristics are definitely affected by the bleaching. In fact, beating curves for unbleached and bleached pulps can only be made to match by setting zero time on the bleached pulp curve at a short interval after the start of the unbleached beating time.

The bleaching of kraft pulps is much more difficult due to the complex nature of the impurities. All steps must be carried under close control. As in sulfite bleaching, chlorination and caustic extraction usually have no deteriorating effect on the pulp but hypochlorite stages must be handled very carefully to avoid damage to the cellulose. Up to 63 to 65 brightness, the hypochlorite stage is easy to control since the reaction is very rapid and low temperatures can be maintained. We believe that the practical limit for bleaching with hypochlorites is about 73. The bleaching stages should be carefully controlled as to temperature and pH.

A great deal has been written about the effect of pH during bleaching. It is our opinion that pH reversals aid in removal of incrustants from the inner walls of the fibre. For instance, following a chlorination stage the pH inside the fibre would be somewhere near 3.0. The caustic addition will produce a pH of about 12.0 on the outside of the fibre. The rate of passage through the fibre walls is accelerated by these great differences.

In the hypochlorite stages, addition of alkalies serves to control the rate of reaction of the hypochlorite. We have found that addition of caustic soda to a calcium hypochlorite bleaching stage is very ineffective since caustic in this form reacts readily with the pulp. On the other hand, calcium hydroxide appears to serve only to maintain the alkalinity of the solution.

It is generally felt that above pH 8.0 little damage is done to the fibre. We feel that reaction time and degree of bleaching is important here too. At the higher brightnesses thet hypochlorite reaction proceeds more and more slowly. This condition can be aggravated to a ridiculous degree by attempting to keep the pH too high. In fact, as in most phases of pulp making, a compromise has to be made between quality and production rate.

We have found conditions of pH in bleaching kraft that result in an off-color end point of bleaching, but giving a brightness jump of up to five points on acidification following washing. The acidification is an important part of the bleaching for either sulfite or kraft. Our experience indicates that bleaching finished at a pH of 8 or above should be acidified to give the highest brightness and most permanent color.

We acidify all of our pulp to a pH of 5.5 with sulfur dioxide solution after the final washing and have found that this step not only improves the color but helps sizing in the paper mill. The alum requirements for pulp that has not been acidified seems to vary over a wide range which often results in poor sizing.

It has also been observed that caustic extracted pulp sizes poorly. This is particularly noticeable in mills after a changeover and it seems to apply to bleached kraft as well as sulfite. One explanation of this is that the so called "hooks" that help hold the sizing are dissolved by the caustic.

Other Bleaching Agents

Sodium hypochlorite instead of calcium hypochlorite is used in some bleach plants. It is, of course, more expensive than the calcium salt and is used in many cases as an outlet for the caustic soda from electrolytic chlorine plants in the mills. We have no information on the effect in the paper making qualities, but without doubt the resulting pulp is chemically more pure and for this reason it is general practice to bleach dissolving pulps in this way.

In the past few years, chlorine dioxide has been under investigation as a bleaching agent by a number of chemical companies and pulp mills. We have had no experience with this material and personally I am not anxious to get too well acquainted with it. It is extremely poisonous and in gaseous form is explosive unless carefully handled.

Chlorine dioxide may be generated in a number of ways among which are:

1. From sodium chlorate by the use of sulfur dioxide as a reducing agent. The resulting chlorine dioxide gas must be immediately diluted with air to maintain the concentration below the explosion point. The dioxide is absorbed in water and applied to the pulp. Patent restrictions, more than the difficulties of this process have retarded its use.

2. From sodium chlorite by acidification of a pulp mixture containing the chlorite with a mineral acid or acidification of the chlorite solution with chlorine gas and then adding to the pulp.

The December 1950 issue of TAPPI carries an article by Ferri Casciani and Gordon K. Storin *(1)* of the Niagara Alkali Company that seems to give a great deal of evidence on the advantages of the use of chlorine dioxide over other bleaching agents. We believe that more work of this sort will result in great improvements in the bleaching of pulps to high brightnesses. Their investigations succeeded in producing plup at 85 brightness that retained substantially all of the unbleached strength.

This same paper also discusses the use of sodium peroxide in kraft bleaching. We have made a few experiments using sodium peroxide as a replacement for part of the sodium hydroxide in a caustic extraction stage but found nothing conclusive.

At the present time we feel that the whole kraft bleaching process is in a great state of change. There are many new reagents to use and many investigations going on, with good possibilities for major process changes. We do feel however that much of the work being done is rushed into print before the results have been proven.

A great many times we have obtained startling results on individual batches but have been unable to reproduce the results. In fact, the only successful development method, in all phases of pulping, is one of check and recheck and then get another sample and start over.

Semibleached Pulps

We have said nothing as yet about semi-bleached pulps. In sulfite bleaching, we start with pulp at 69 brightness which color is obtained by caustic extraction of the raw pulp, followed by a single stage of high density bleaching. The same method is used for bleaching to a brightness of 76. It is also possible to obtain the 76 brightness by chlorination, followed by hypochlorite bleaching, but it usually takes more chlorine and the pulp is much dirtier. Caustic extraction of these low brightness pulps improves the cleanliness and reduces chlorine consumption.

Large amounts of Kraft pulps are also semi-bleached here. We used to make 45, 55 and 60 brightness pulps but have now gone up to 63. The 45 and 55 brightness pulps were made with single stage hypochlorite. After much experimentation with 60 brightness pulps in our 1935 bleach plant, we finally settled on the hypochlorite bleaching in three stages. By careful scheduling in the plant, and by virtue of the high bleaching rate at these low brightnesses, we increased the capacity of the plant from 35 to 60 tons per day. The multiple stages gave us maximum chlorine economy and easily controlled brightness. All semi-bleached pulps are difficult to bleach to uniform brightness since a small excess of bleach liquor will result in over-bleaching before the reaction can be stopped. Complete exhaustion of the bleach results in color reversion.

We now bleach considerable tonnage of kraft to 63 brightness. At this color we have a choice between all hypochlorite bleaching or chlorine, caustic, hypochlorite. The chlorine economy is about the same but the strength is better with chlorination.

Instrumentation

Temperature recorders were practically the only control instruments in early bleach plants. With modern continuous plants, many types of instruments must be used. Pulp flows are now controlled by metering devices and level controllers. Chemical flows are also continuously metered through rotameters or other types of flow meters equipped with either manual or automatic ratio control. Temperatures are now automatically controlled and drives and valves are usually operated by remote controls, some automatically.

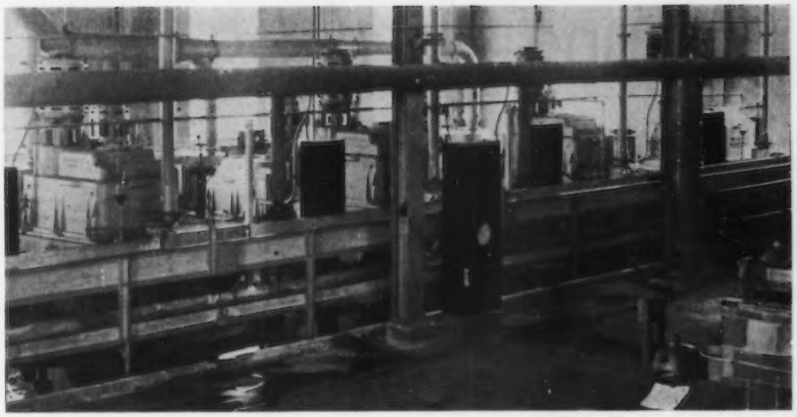

Photo Showing Conveyor Belt Feeding High Density Caustic Cookers and Also Agitator Motors for Each Cell

An interesting development in process instrumentation is the combination flow chart and control panel. A panel is made up in flow diagram form with each vessel in outline and small instruments mounted at the control points.

Continuous bleaching at high rates requires large volumes of reagents. The greatest problem is bleach liquor making. Very few plants have tried to solve this by continuous processes. The usual method has been to use a small absorption tower with lime water and chlorine flowing counter-currently. In common with many others, this chemical reaction results in a temperature rise which is directly proportional to the amount of chlorine absorbed. We believe that this temperature rise furnishes a means of controlling the reaction automatically and have been experimenting with methods of doing this.

The continuous production of bleach liquor solves the problem of lost time in the conventional batch liquor tank. After the liquor is made, the settling tanks offer another chance to reduce plant size. One of the prominent chemical manufacturers has been advocating the use of unsettled bleach liquor for some years. Most bleach plant operators have, at one time or another, had unpleasant experiences with the production of extremely dirty, off-color bleached pulp from bleach liquor containing sludge from settling tanks. These experiences have resulted in a great deal of resistance to the use of unsettled bleach liquor.

We have experimented with unsettled bleach liquor in our plant. The suspended matter is normally calcium hydroxide which in controlled amounts, will act as a buffer to provide uniform pH control in hypochlorite bleaching without causing bad effects.

However, there are a number of methods of clarifying liquids containing suspended matter that may be used to produce clear liquor if desired.

Caustic soda systems lend themselves well to continuous handling methods. The most common method of delivery to mills is 50 percent liquid caustic in tank cars. Our storage tank for strong caustic has a capacity of almost two tank cars. The 50 percent caustic is diluted to a 10 percent before using. It is entirely practical to make this dilution continuously by use of meters and ratio controllers.

Conclusion

To summarize, it might be of interest to review the bleaching methods in common use.

Sulfite

Chlorination, caustic extraction hypochlorite, acidification.

Kraft

1. Chlorination, caustic extraction, hypochlorite, acidification.
2. Chlorination, caustic extraction, hypochlorite, caustic extraction, hypochlorite, acidification.
3. Chlorination, soak, caustic extraction, soak, hypochlorite bleaching.
4. Chlorination, chlorination, caustic extraction, hypochlorite bleaching, caustic extraction, hypochlorite bleaching.
5. Chlorination, caustic extraction, hypochlorite, caustic extraction, chlorine dioxide.

Special method advocated by Casciani & Storing *(1)*.

1. Chlorination, hypochlorite, chlorine dioxide, sodium or hydrogen peroxide.

The choice of these methods is pretty much determined by local factors. We believe that many of the above systems will soon be obsolete because of rapid rate of new developments.

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Chlorine Bleaching

John C. Cousins[1]

Introduction

By bleaching we mean the removal of colored materials from the pulp. Various textbooks and articles cover the chemistry of bleaching reactions very thoroughly. I shall, therefore, consider mainly the practical side. The practical application sometimes complicates the chemistry.

Although my experience has been mainly with sulfite pulp, I know something about soda pulp as we have both soda and sulfite mills at Great Works.

Sulfite pulp is ordinarily very easily bleached. It can be bleached in a single stage to a reasonable degree of brightness without serious loss of strength. By reasonable, I mean 75 to 78 General Electric brightness. Beyond this brightness it requires different treatment. Perhaps the most accepted method of bleaching is by using three stages. First the pulp is chlorinated, then treated wtih alkali, and finally bleached with hypochlorite.

Chlorination

First let us consider chlorination. This is usually done in one or more towers, ordinarily made of wood, and of such size that based on the production of the mill a reaction time of one hour will be attained. The pulp and the chlorine (either absorbed in water or as a gas) are mixed, and admitted to the top of one tower shown schematically in *Figure 1.* They flow down through this tower and cross over at the bottom of it into a second tower through which they pass upward. On reaching the top of the second tower they overflow onto a washer.

The first 15 to 20 minutes time of contact will consume 90 to 95 percent of the chlorine. The remaining five to ten percent takes a much longer time to react. Theoretically, the chlorine should probably not be all exhausted because the reaction changes to one of oxidation before the chlorine is all consumed. From a practical standpoint, however, as much of the chlorine as possible must be used up in order not to release it into the air in any quantity. This chlorine if released into the air when the pulp is admitted to the washer makes an extremely dangerous condition for the health and comfort of mill personnel.

Caustic Treatment

After the pulp leaves the tower it must be washed. Many types of washers are available for this purpose and the type of washer used usually depends on the treatment following chlorination. The chlorination has formed many water soluble chlorides but also has formed a large number of chlorides that are alkali soluble. The washer chosen, therefore, must leave the pulp at the proper consistency for a caustic treatment. There are many systems of caustic treatment utilized in various places, low density, high density, with or without increase of temperature, and with varying amounts of alkali. The method that seems to work best, is to use a high density extraction, following chlorination, at about 15 to 18 percent consistency, at a temperature of 140 to 150 degrees Fahrenheit, and a fairly short reaction time. The reaction time 20 to 30 minutes is usually ample. This treatment will dissolve these soluble chlorides and put them in a condition where they may be washed out again in another washing operation similar to the previous one.

The equipment for a high density caustic treatment is usually a vessel made of iron and it may have an internal worm similar to high density bleachers. In fact, it is nothing more or less than a regular high density bleacher adapted for use with caustic. Another method is to pump stock into the bottom of a vessel by a particular type of high density pump, and let it overflow at the top. The type of vessel with a worm in it must be, for the most part, a batch system. It cannot be run continuously because it will not circulate properly which results in a lot of caustic in one place with only a little in an other. It just does not lend itself to good mixing if you are trying to bleed it off. But with the other method utilizing a special high density type pump with no tube in the middle and overflow at the top reaction time can be based on the height of the vessel.

In order to determine the size of any of these vessels it is necessary to consider the density of the stock in them, the time needed for reaction, the amount of production of the mill and from these the amount of space needed for reaction can very easily be figured. Sulfite pulp and soda pulp will lend themselves quite readily to this type of treatment.

With kraft that is something else again. Kraft pulp cannot be conveniently bleached in one chlorination. It should normally have at least two caustic extractions after chlorination and in some cases, I believe, it has as many as three or four depending upon the type of pulp, the degree of cooking, and how much material there is to be removed.

Chlorine Demand. Let us now get back to sulfite pulp. We have chlorinated it. In chlorinating it we first have to know the so-called bleachability as represented by Roe's chlorine number, or by any of a number of other determinations. In the chlorination stage, for best results in chlorinating the pulp sufficiently, and not

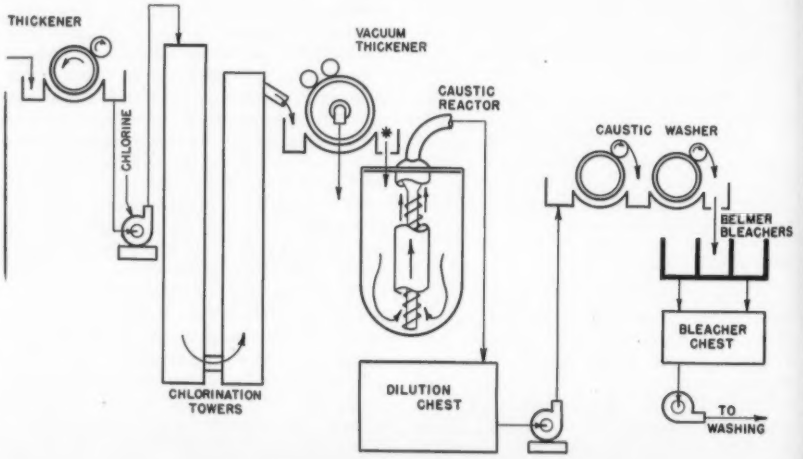

Figure 1—Typical Three Stage Bleaching System

[1] Chemist Sulfite Division, Penobscot Chemical Fibre Co., Great Works, Maine.

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3 **Give you cleaner finished paper** — with a minimum reversion of brightness!

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Our line of caustics — liquid, flake, powder, and Crystal*— fills every paper-making need. You'll find savings in coating, too, by using our precipitated calcium carbonate, PURECAL* M; and find that our soda ash and chlorine meet your highest specifications. Write for complete information. *Wyandotte Chemicals Corporation, Wyandotte, Michigan. Offices in Principal Cities.* *TRADEMARK

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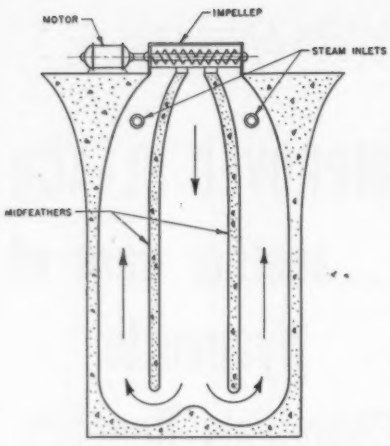

Figure 2—Belmer Bleacher

leaving too much dirt behind which will not be chlorinated appreciably, 50 to 60 percent of the bleachability figure is about all the pulp will stand. If you run above that, the bleaching action will work all right on the pulp but not on other materials that are quite generally there. Some of the biggest offenders are perhaps small pieces of bark which are too small to screen out and little pieces of uncooked wood that have passed the screens. They do not lend themselves well to chlorination but can be bleached with hypochlorite later, if enough work is left to be done by hypochlorite.

The chlorination at these figures and the subsequent washing with alkali will reduce the bleachability more than the percent of chlorine would indicate. A multi stage bleaching system will save a considerable amount of chlorine over that required in a single stage.

Hypochlorite Stage

For the final bleaching of pulp, there are again many systems in operation. All of these have their advantages and disadvantages. The most preferred system at the moment is perhaps high density bleaching, carried out usually as a batch process.

High Density. The high density bleacher is just exactly the same as the high density caustic reactor. It is a vessel with a worm in the center to circulate the stock from bottom to top. The stock is fed in and the amount of bleach to be added is calculated from a sample taken continuously over the feeding period. After the bleach is added, the pulp is circulated for the length of the reaction time which is roughly four to five hours but, in some cases, considerably less depending on whether the pulp is easy or hard bleaching. The pulp is then usually dumped into a fairly large tank that will hold pulp from several bleaches and is diluted considerably. The reaction is perhaps not wholly stopped when the stock is dumped but it is, at least, slowed down so that it is not reacting appreciably and the pulp is held in a state of inactivity until there is room in the rest of the equipment to wash it.

Low Density. My own experience has been mainly with low density belaching in a Belmer type bleacher. Looking down on top of a Belmer you see, *Figure 2,* a fairly large tank with two midfeathers in it. The circulation of the pulp is indicated with a worm to drive it. The pulp may be pumped to the Belmer, fed in by felt conveyor, or fed by a screw conveyor, whatever, means the mill happens to be using. We use a belt conveyor at the moment. Not too long ago, we discarded a pump. Either method is satisfactory. The pulp is fed in and again the amount of bleach is determined usually from a continuous sample taken over the period of filling. The necessary amount of hypochlorite is then added to the stock.

Here we run into a problem of pH. The chlorination takes care of its own pH quite nicely in that it keeps the pulp out of the range of 2 to 7.5, where the most damage is done to the fibers. In the hypochlorite bleaching operation that is not true. Providing the pulp is well washed and fairly near the neutral point on entering the bleacher, the addition of hypochlorite will probably raise the pH to around 9 and this will very rapidly decrease until after it has been in the bleachers for roughly two hours when it will be down around the neutral point. From there on with an 8 or 10 hour bleaching time, most of the bleaching will be done in a slightly acid condition which is extremely destructive to the fibers. It removes the lignin material very nicely but it also destroys many, particularly the weaker, fibers resulting in loss in pulp strength and pulp yield. In the hypochlorite bleaching stage, therefore, it is necessary to add lime or alkali of some kind, again usually sodium hydroxide, in order to keep the pH from going much below 8 which seems to be a good safe place. It can go below that without too serious damage, but it is a delicate balance to maintain it just below that.

Another problem now is the slowing up of the bleaching reaction by the addition of lime or caustic to a point where it is going to be too long for the equipment and the time available to handle it.

The amount of bleach added which is controlled by the bleach requirement of the pulp, makes a lot of difference in dropping the pH value. If we have a pulp that only requires five or six percent bleach in this stage of bleaching and we start off with alkali enough to have a pH of about 11, we end up with the final pH in the range of 7.5 to 8.0 which is right where we want it. Then if somewhere in the mill process, in the digester or some other place, something goes a little haywire and we go into those same bleaches with the same pulp that has had practically the same chlorination, but the bleachability has gone from perhaps 5 up to 10, then we start in the bleachers with the same pH of 11. We find, perhaps after about five hours, the pH drops right down to the neutral point or slightly below. It stays there pretty well but is still too low. If the additional alkali is added at the start of the bleaching process, the reaction is going to slow up so much that with the equipment we are using, which is six Belmer bleachers, and the rate of production we are putting through them, the bleaching time cannot be maintained long enough to get the desired brightness of pulp without an excessive use of temperature on the bleachers.

Also in hypochlorite bleaching, temperature, or particularly lack of temperature, is an important factor. The violence of the reaction, when the temperature is raised rapidly, reduces a good many of the fibers to practically nothing. The safe upper limits in this type of bleaching in Belmers at about six percent consistency is perhaps 100 degrees Fahrenheit. Even then you can expect some losses. If held down to 90 degrees Fahrenheit you will see a fairly substantial increase in the amount of pulp.

Conclusion

It is still a hard thing to pin down a bleaching system that will satisfy every type of mill, and every type of pulp, and have some company turn them out tailor made and say here it is, come and get it. Set it up and treat it thus and it will work. It will "if." If you happen to have the particular characteristics of pulp that adapt themselves to that type of treatment. Mills all over the country are continually changing their ideas and methods of bleaching. It is perhaps one of the largest fields for experimental work that there is today.

There are on the market today many instruments all aimed at giving better control of the bleaching operation automatically. Instrumentation in the bleaching operation is a large field and I will not attempt to discuss it as I believe you will have a talk later on instrumentation in the pulp and paper industry.

Corrosion-Resistant Metals for Pulp and Paper Industry

Daniel L. Horigan
Development Engineer, Lukenweld[1]

1942—B.S. in Management Engineering, Carnegie Institute of Technology; Plant Layout, Mine Safety Appliances Co., Pittsburgh, Pa.; Process Engineer, Inland Manufacturing, Division of General Motors Corp., Dayton, Ohio; Field Engineer, Cone-Drive Division, Michigan Tool Co., Detroit, Mich.

Much of the equipment used in pulp and paper mills is threatened by corrosion. Before explaining how modern equipment builders guard against such attacks this article will first deal briefly with the various types of corrosion which are apt to be encountered; the second part will deal with the properties of the various corrosion-resistant metals and the forms in which these metals are available; and the final part will deal with specific applications in pulp and paper processing.

PART I

Forms of Corrosion

The most common forms of corrosive attack are:

1. *General Attack.* This is what is normally called rusting or simple oxidation and is the type of corrosion most familiar to the average person.

2. *Galvanic Attack.* This type of corrosion occurs in equipment when two metals (or two phases of composition in one metal) are present in an electrolyte, i.e. a solution that will carry a current. Metals at one end of the galvanic series (anodic, electropositive, or least noble) such as magnesium, zinc, carbon steel and others are easily corroded; while the metals at the other end (cathodic, electronegative, or most noble, such as platinum, gold, silver, graphite, Monel and the following (when passive): stainless steels, nickel and Inconel are difficult to corrode. In the complete galvanic table, the relative position of any two metals determines their rate; the closer together, the less chance of corrosion. The relative area of the two metals and their distance from each other will also govern the corrosion rate, provided conditions are such that both anode polerization and resistance drop can be neglected. If the area of the anodic metal is greater than that of cathodic metal, generally no corrosion will occur; if the opposite is true, corrosion of the anodic metal will be very rapid. The electrical conductivity of the solution handled may also affect the speed of attack.

3. *Pitting* (Concentration cell corrosion). Chlorine and certain other reducing solutions in equipment will sometimes cause attack on steels containing chromium; the negative chloride ion in aqueous solutions causing a localized condition known as pitting, or concentration cell corrosion. Pitting results when a local breakdown of the passive film occurs, wherein the anodic area is much less than the surrounding larger cathodic area.

[1] A Division of Lukens Steel Co., Coatesville, Pa.

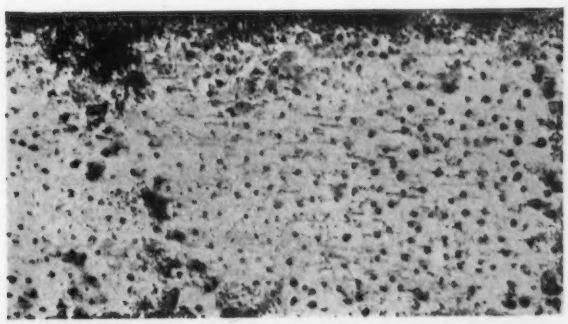

Figure 1—Example of severe surface pitting on surface of Type 410 Stainless Plate.

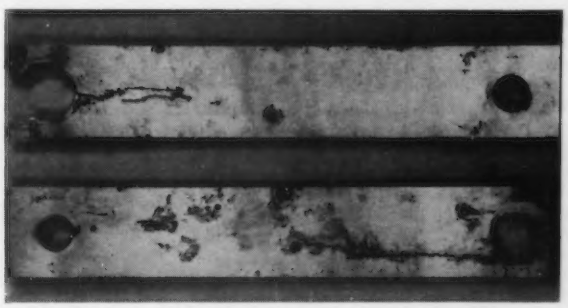

Figure 2—Illustration of effects of concentration cell corrosion. The two sheet samples of Type 304 Stainless (0.05" thick) were insulated and mounted on bakelite washers and exposed to sea water for 60 days. Areas under washer at upper left and at lower right corroded away. Original bolt hole size shown at lower left.

GALVANIC SERIES TABLE

Corroded End (Anodic)

	Magnesium	
	Magnesium Alloys	
	Zinc	
	Cadmium	
	Carbon Steel	
	Copper Steel	
	Cast Iron	
AISI Types:	4 to 6% Cr. Steel	
(410)	12 to 14% Cr. Steel	Active *
(430)	16 to 18% Cr. Steel	
AISI Types:	Ni-Resist	
(304)	18% Cr., 8% Ni. Steel	
(309)	23% Cr., 14% Ni. Steel	Active *
(310)	25% Cr., 20% Ni. Steel	
(316)	18% Cr., 12% Ni., 3% Mo Steel	
	Lead-Tin solder	
	Lead	
	Tin	
	Nickel (Active *)	
	15% Cr., 60% Ni. Inconel	Active *
	20% Cr., 80% Ni.	
	Brasses	
	Copper	
	Bronzes	
	Nickel-Silver	
	Copper-Nickel	
	Monel	
	Silver Solder	
	Nickel (Passive *)	
	15% Cr., 60% Ni. Inconel	Passive*
	20% Cr., 80% Ni.	
AISI Types:	12% to 14% Cr. Steel	
(410)	16% to 18% Cr. Steel	
(430)	18% Cr., 8% Ni. Steel	Passive *
(304)	23% Cr., 14% Ni. Steel	
(309)	25% Cr., 20% Ni. Steel	
(310)	18% Cr., 12% Ni., 3% Mo Steel	
(316)	Silver	
	Graphite	
	Gold	
	Platinum	

* These designations as active and passive will be covered in Part II. Note that metals in the passive condition are more noble than the same metals in the active condition.

Protected End (Cathodic)

Once pitting starts, it proceeds so rapidly that metal thicknesses alone offer slight protection. (See *Figures 1 and 2.*)

4. *Intergranular Corrosion.* Corrosion of this type is caused by the phenomenon known as sensitization or carbide precipitation. It is a characteristic of the austenitic (chrome-nickel) stainless steels — being the harmful precipitation of a grain boundary constituent in a certain temperature range between 850° and 1500° F. The most serious and most rapid precipitation occurs at the mid-point of this range and can occur as a result of slow cooling through this range or by welding (See *Figure 3*). In a corrosive medium separate grains will flake off from a sensitized stainless steel — giving this type of corrosion its name. The four most practical ways of avoiding sensitization are as follows: 1. annealing the metal—heating it to a high enough temperature and holding it long enough to dissolve all chromium carbides. Temperature range is 1800°-2150° F. and time is usually one hour per inch of thickness. It is then rapidly cooled. 2. Another method is to restrict the time the steel is held in the sensitization range. This may be difficult to do during fabrication. 3. A third method is to lower the carbon content to a .03% to .04% maximum, which prevents the formation of any appreciable amount of carbides. These steels are known as Extra Low Carbon-E.L.C. 4. A fourth method is to add an alloying element to the steel which will have a greater affinity for carbon than chromium and whose carbides will not damage the alloy. Titanium and columbium are the two principal elements used for this. Type 321 is titanium stabilized, Type 347 columbium stabilized. Columbium is on the critical list today, hence Type 304 the low carbon and Type 321 materials are finding extensive current use in lieu of the previously preferred Type 347 stainless.

A similar phenomenon occurs in nickel due to the fact that nickel is not stable and carbon is insoluble in the solid state. Carbon, in the form of graphite, precipitates along grain boundaries and in the grain of nickel in the 700°-1100° range. When operating in this range it is common practice to use low carbon nickel (.02% carbon max.).

5. *Stress Corrosion.* Corrosion of this type occurs in equipment when certain metals are stressed in tension highly enough to produce plastic deformation and are also exposed to the proper corrosive medium. It is believed that this plastic deformation may cause the highly stressed material to become less noble than the less strained material, and the corrosion of the highly stressed material will be accelerated by galvanic effects between the stressed and unstressed portions in the electrolytic solutions. Stress corrosion cracking of steel in alkaline solutions is what is commonly called caustic embrittlement. Failure occurs sometimes through grains, and sometimes along grain boundaries depending upon the metal and other factors. Certain mediums are more conducive to attack than others, chlorides being particularly severe on stainless. This problem has received attenion recently because of the costly failures that ensue when it occurs. When this type of corrosion begins it may proceed to completion within a matter of hours. Salvage or weld repair is rarely possible, even if noticed in time. Proper design and metal selection to reduce high stresses is essential in preventing this type of attack (See *Figure 4*).

6. *Crevice Corrosion.* Closely associiated with concentration cell corrosion, crevice corrosion is caused in equipment (*Figure 5*) because a passive film is prevented from forming in a crevice or tight joint and a concentration cell may be set up. Elimination of all crevices, including the use of a crack-free surface, is the best protection.

7. *Erosion-Corrosion.* Continual removal of the passive film is believed to be the principal cause of this type of corrosion in equipment, which occurs under conditions of mechanical abrasion or dynamic flow.

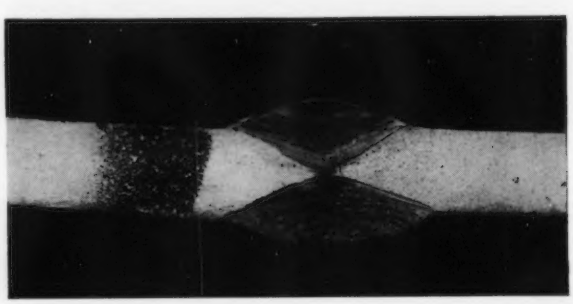

Figure 3—Intergranular corrosion (left) is shown alongside Plate (right) of butt weld in Type 304, Stainless plate. Type 321 shows no weld sensitization.

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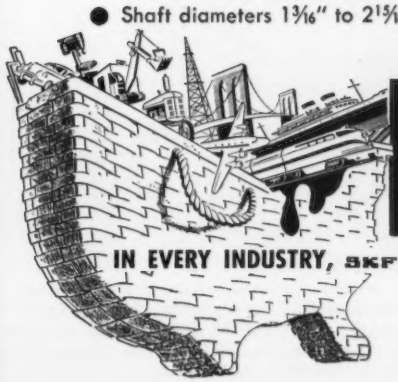

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Figure 4—Stress corrosion cracking in Type 304 stainless plates. Section through crack, unetched, has been magnified about 200 diameters.

8. *Cavitation Corrosion.* This type of corrosion occurs in equipment in the presence of cavitation which is basically a dynamic action within a fluid with a periodic formation and collapse of cavities in regions below the residual absolute barometric pressure. The net result is a deterioration of the surface out of all proportion to what might be expected from simple corrosion. Eddy current areas, orifices, nozzles, pump impellers, and turbine locations are frequent points of attack. (See *Figure 6*).

More than one type of corrosion may occur simultaneously, one type frequently leading the others in the same vessel, as will be explained in subsequent sections.

PART II

Corrosion-Resistant Metals

This section will deal with the properties of various corrosion-resistant metals and the forms in which these metals are available. The discussion is confined to the nickel-base metals—Monel, nickel, and Inconel—and the stainless steels.

Nickel-Base Metals

As can be seen in the galvanic series, the nickel-base metals are relatively noble. They require oxygen or some other oxidizing agent for continuation of their corrosion reactions. As a result, they exhibit their highest degree of resistance to acid corrosion under reducing conditions and tend to have their corrosion accelerated by oxidizing acids and compounds.

Monel. (63-70% Ni; 30-37% Cu) is most versatile since it resists the attack of mineral and organic acids, alkalies, and salts over a wide range of concentration and exposure conditions.

Nickel. Is similar to Monel in its corrosion resistance; it is generally inferior in resistance to acids, about the same in resistance to salts, and a little better in resisting alkalies. "A" Nickel is the wrought form most commonly used. It is commercially pure nickel. The Low Carbon Nickel (0.02% Carbon Max.) is used under conditions mentioned under Part L, Point 4.

Inconel. (75% Ni; 12-15% Cr.; 9% Fe) was developed primarily to resist corrosion and tarnishing by foods as well as to protect their purity. It is also superior to Monel and Nickel in resisting strongly oxidizing acid solutions and dilute organic acids. However, the oxidizing effect of dissolved air alone is not sufficient to give Inconel an appreciable advantage over Monel or nickel in aerated mineral acids or concentrated organic acids. Inconel possesses superior resistance to alkaline sulfur compounds and hydrogen sulfide at atmospheric and elevated temperatures.

Stainless Steels*

Class I. Martensitic. The principal characteristic of these alloys distinguishing them from other stainless steels is their ability to harden by a heat treatment that produces martensite. Chromium in the lower stainless range (12 to 17%) is the sole major alloy addition, and the carbon is the next most important addition. Carbon has a wide range, and small amounts of other elements may be added, but the metallurgist always views the composition with respect to hardening ability. These steels are therefore popularly referred to as the *martensitic stainless steels* or the *hardenable stainless steels*; also occasionally the *straight chromium stainless steels.* These terms are popularly used interchangeably. Steels in this class are magnetic.

Class II. Ferritic. Principal characteristics of this class are a surpassing corrosion resistance and an inability to harden by martensite formation. Chromium in the upper stainless range (18 to 30%) again is the sole major alloy addition. Limited contents of carbon and other minor alloy additions provide no appreciable martensite; the microstructure is predominently "ferrite." Popular terms include *ferritic stainless steel* (because of this characteristic and unchanging ferrite phase); *nonhardening stainless steel;* and again, *straight chromium stainless steels,* or irons. Steels in this class also are magnetic.

Class III. Austenitic. The principal characteristics of this Class are the ductile austenitic condition, the work hardening which develops during cold working, and superior corrosion resistance. Chromium (roughly 8 to 30%) and nickel (roughly 6 to 20%)

* Definitions here are according to "Stainless Steels" Ref. 2, by Carl A. Zapffe, American Society for Metals, 1949.

Figure 5—Crevice corrosion in Type 304 stainless disc. Attack occurred underneath three washers which excluded air, when disc was exposed to mold acid attack.

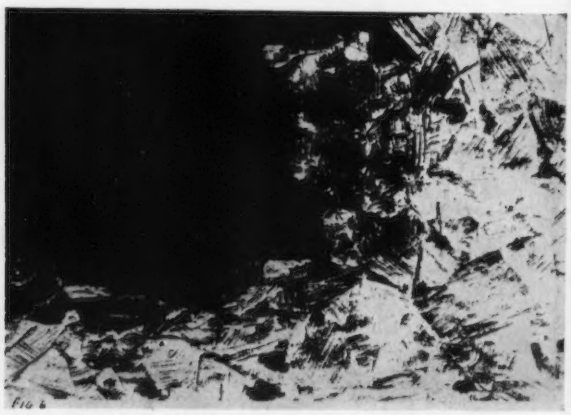

Figure 6—Cavitation corrosion in Type 304 stainless plate shown in photomicrograph (mag. 200x). Sample was cut through corroded section. Solid dark portion shows loss of metal due to cavitation. Metal edges illustrate cold working resulting from attack. White line shows original plate surface.

both as major alloy additions, with carbon held low. Other elements are added, but with respect to the balance of the austenite phase now made stable by the presence of a major proportion of nickel. An austenitic stainless steel is one which cannot be hardened by heat-treatment. This class is divided into three groups—work hardening, free-spinning and alloy modification. Among developments in the third group are "precipitation hardening" alloys which permit the steel to be worked and formed in the soft condition and then hardened and strengthened at moderate temperatures which neither warp nor oxidize the structure. Popular terminology for Class III includes *austenitic stainless steel* (because of the essentially stable austenite phase); *chromium-nickel, work hardening,* and *18-8 stainless steels.* Steels in this class are non-magnetic in the annealed and unworked condition.

Under AISI (American Iron and Steel Institute) type numbers, the Class I and Class II stainless steels fall in the "400" series; and the Class III stainless steels fall in the "300" series. These type numbers should be used to designate the exact grade of stainless under consideration, rather than simply saying "stainless steel," or giving the broader descriptions shown under the three class headings, as this can avoid unnecessary misunderstandings or even service failure due to improper selection of materials.

Passivity. With this general background, the next subject is a discussion of passivity, the phenomenon that makes stainless steel corrosion-resistant.

Passivity in stainless steel is directly dependent upon the chromium content. It is a condition of negligible corrosion, rather than non-corrosion. It is definable as a phenomenon causing impedance to corrosion reactions involving metals and alloys whose tendency other wise is to react with the surrounding medium. Furthermore, passivity is only a relative term, for a steel passive in one medium may corrode in another.

The exact nature of passivity is probably not known but a popular theory assumes the existence of a protective film which greatly retard further attack of the metal and whose existence, or non-existence, determines the difference between being passive and normal activity. A rather simple analogy occurs during the evaporation of water. There the conversion of water into vapor can be likened to corrosion, since the substance is passing into another form through the influence of natural forces. In the open, the water slowly evaporates, or "corrodes" away. However, if the thinest film of oil or paraffin completely covers the surface, the escape of vapor is virtually stopped, and a condition of passivation is attained.

Also in question is the exact nature of the film responsible for the passivation of stainless steel. Without going into the details of this matter, it may be simply said that the presence of a continuous and chemically protective surface layer, possibly an oxide, is not unlikely. There is evidence completely in keeping with the supposition that a protective surface film attemps to form with increasing chromium content, when conditions are oxidizing, and that it rather suddenly completes itself when about 12% of chromium is present in the alloy. (*See Figure 7*). It will probably be safe to assume that with stainless steel an oxide surface layer conceivably forms which is tenacious and quite impenetrable to migrating atoms—either oxygen atoms pressing inward, or metallic atoms pressing outward—thus passivating the corrosion action; and conversely, when that film is destroyed by certain chemical or mechanical action, the steel depassivates (or activates) and becomes liable to attack.

Stainless steel, in their passivated state, rank next to the noble metals in the galvanic series, with the "300" series being more noble than the "400" series. Stainless steels are most resistant to acid corrosion under oxidzing conditions, and tend to have their corrosion accelerated by reducing acids and compounds which destroy their passive film.

Straight Chromium Types

Type 410 is a straight chromium martenistic containing just enough chromium (11.5 to 13.5%) to attain stainlessness, and minimum of carbon for obtaining a wide range of mechanical properties without incurring either permanent carbides or the demanding care required in handling highly hardenable grades. It is slightly air-hardening when cooled from high temperatures and also has good resistance to oxidation and corrosion at high temperatures with minimum cost. Type 410 with 0.08% max. carbon, and in the clad form, is easier to weld.

Type 405 is essentially a 12% chromium stock of Type 410, made ferritic by an addition of aluminum instead of further chromium. Just sufficient aluminum is added to prevent important quantities of austenite (and hence, any martensite upon cooling) from forming at elevated temperatures. This feature becomes extremely important during welding—for example, in such operations as lining a digester, since an annealing operation to relieve stresses due to the formation of martensite near the weld would be cumbersome and expensive, if possible at all. The alloy therefore provides dimensional stability and corrosion resistance where great strength or hardness is not required, and at a minimum of expense. It has found an increasing acceptance for high temperature applications due to the better heat resistance imparted by the aluminum addition. It should be noted that difficulty has occasionally been experienced with this type due to a heat having unexplained hardenability.

Type 430 is similar to Type 410 but with the chromium content increased into the 14 to 18% range without a corresponding increase in carbon or nickel, whereupon half or more of the alloy is converted permanently to ferrite. Thus it has excellent resistance to oxidation, scaling and corrosion at high temperatures. However, the heat-affected zones of welded solid steels of this type may be brittle and have little ductility. In clad steels the overall weld joint efficiency is improved because a large portion of the joint's

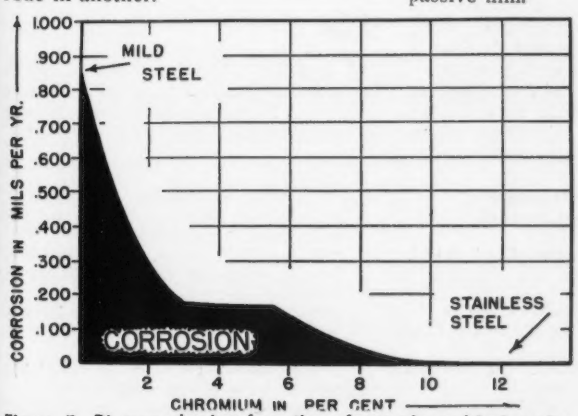

Figure 7—Diagram showing formation of corrosion-resistant protective film. (Courtesy American Society for Metals, "Stainless Steels," Carl A. Zapffe.)

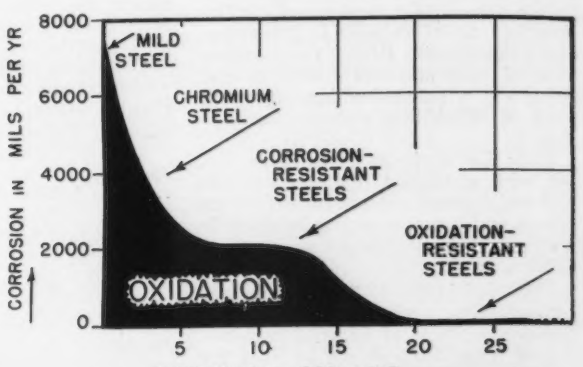

Figure 8—Diagram showing improvement in resistance to oxidation. (Courtesy American Society for Metals, "Stainless Steels," Carl A. Zapffe.)

cross section is carbon steel which is not as subject to grain growth and brittleness as is solid Type 430.

Chromium-Nickel Types

Type 301 is a 17-7 chromium-nickel alloy used under comparatively mild corrosive conditions. Its major use is in wrought products where high structural strength can be developed with moderate cold working, such as wire, sheet and strip, under conditions of atmospheric exposure.

Type 302 is the basic 18-8 type with 0.08-0.2% carbon having excellent corrosion resistance for sanitary and decorative purposes.

Type 304 is an 18-8 type with 0.08% max. carbon. Due to the limitation of the carbon content, this steel is less susceptible to carbide precipitation during welding than Type 301 and 302 and may be used over a wider range of corrosive conditions without subsequent heat treatment. This material is available with 0.03% max. carbon in solid form and 0.04% max. in clad form.

Type 309 has a higher chromium and nickel (25-12) content than the basic 18-8 and has superior resistance in a large variety of service conditions combining heat and corrosion. *(See Figure 8)* It is popular for welding electrodes because it provides ductile weld metal.

Type 310 has the highest chromium and nickel (25-20) content of the austenitic stainless steels regularly produced. It has the best resistance to oxidation at high temperature of any stainless. Its higher cost is an important factor retarding its wider use. It is also popular for welding electrodes for the same reason Type 309 is used.

Type 316 is the 18-8 type of higher nickel (10% min.) content with the addition of 2.0 to 3.0% molybdenum. It is sometimes referred to as a 16-13-3 rather than 18-8 Mo. The great advantage of the molybdenum is the increased resistance it offers to pitting by solutions containing chloride ions. Type 316 can be used with sulfuric and sulfurous acids, sulfite and cellulose solutions; and is of special service to the paper, pulp, rayon and dye industries. It is available in three special grades—with 0.03% max. carbon in solid form and 0.04% max. in clad form and a columbium-bearing grade —all of which help prevent sensitization.

Type 317 is the same as Type 316, but with a silghtly higher chromium and molybdenum content to further increase resistance to pitting by chloride ions, under atmospheric exposure conditions.

Type 321 is the 18-8 type stabilized by the addition of titanium to prevent the precipitation of harmful carbides. It (or Type 347) should be used for welded vessels under certain corrosive conditions, or if the service temperature range is 800° to 1600° F., or if the vessel is to be stress-relieved. It may be employed over a wide range of corrosive conditions without subsequent heat treatment and will also withstand heat treatment without becoming sensitized. As titanium cannot normally be transferred through the arc, columbium-bearing (Type 347) electrodes are used for welding Type 321 material.

Type 347 is the same as Type 321 except that columbium is used as the stabilizing element, to prevent the precipitation of harmful carbides. Columbium forms extremely stable carbides preferentially to chromium and prevents the sensitization phenomenon. This material is used for welded vessels under certain corrosive conditions, or if the service temperature range is 800° to 1600° F., or if a weldment is to be stress relieved.

Next to be discussed is a comparison of four of the physical properties of these various metals in relation to carbon steel. This is important in fabrication and welding, and also in determining suitability of any material for the conditions of heat or heat transfer which may be encountered in a given application.

Electrical Resistance of the chrome-nickel alloys is about six times that of plain, or carbon steel, increasing to twelve times when extremely cold-worked; straight chromium alloys have three to six times that of carbon steel; Monel is about five times that of carbon steel; nickel is about the same as carbon steel; and Incomel is about ten times that of carbon steel.

Heat Conductivity of the chrome-nickel alloys is about one-quarter of that of carbon steel; one-quarter to one-third as much for the straight chromium alloys; one-half as much for Monel; the same for nickel; and one-quarter as much for Inconel.

Coefficient Expansion of the chrome-nickel alloys is about one and one-half times that of carbon steel; the same or slightly less for the straight chromium alloys; about one-sixth more for Monel; about one-tenth more for nickel; and slightly less for Inconel.

Melting Point of the chrome-nickel alloys, the straight chromium alloys, Monel, nickel, and Inconel is just a little less than that of carbon steel.

The variation in these four physical properties, plus the wide variation in tensile strength and ductility, show why corrosion resistance is not the sole factor to be considered in choosing a metal. A fabricator may unwittingly set up ideal conditions for one or more of the common types of corrosion by wrong material selection or by trying to maintain and correct for extremely close tolerances. By proper material specification and proper tolerance limits, this danger can be eliminated.

A consideration of the various forms in which these metals are available will follow. It will simply mention castings, bar, rod, and wire without going into any detail. Plate, sheet, and strip will be dealt with at some length.

Plate

That group of flat-rolled products over 3/16″ thick and 10″ wide is known as *plate*. It comes in five general classifications:

1. As hot rolled (most common variety).
2. Heat treated (usually annealed).
3. Heat treated and cleaned or descaled (by pickling or sandblasting; or by sodium hydride descaling of nickel-clad, all types of stainless-clad, and Inconel-clad plate).
4. Heat treated, cleaned, and cold rolled (for plates under ¼″ thick).
5. Heat treated, cleaned and polished.

Clad Steels. Clad steel plates in flat form are available in three polished finishes:

1. Standard No. 4 Finish—A surface normally furnished when a commercial polish stainless steel is specified. The corrosion-resistant clad surface is ground with consecutively finer abrasives until all imperfections on the face are removed.
2. Luster Finish—Comparable in appearance to a No. 4 sheet finish but is somewhat smoother to the touch. It is not necessarily 100% pit-free.
3. Super-Luster Finish—This finish is somewhat brighter and smoother than a No. 6 sheet finish, but not as bright as a No. 7 sheet finish.

Sheet

A rolled product less than 3/16″ in thickness and more than 24″ wide is defined as *sheet*. Stainless sheet comes in seven standard finishes:

Finish	*Designation*	*Remarks*
.....	Hot Rolled and Annealed.	Dark oxidized surface; satisfactory for furnaces, ports, chutes, or bins.
No. 1	Hot Rolled, Annealed and Pickled.	"White-pickled" surface, suitable for deep-drawing articles not requiring polishing or buffing.
No. 2D	Full Finish; Dull. (Same as No. 1 plus Cold Rolled, Annealed and Pickled).	Suitable for forming, spinning, deep-drawing, polishing, or buffing.
No. 2B	Full Finish; Bright. (Same as No. 2D plus Cold Rolled).	Bright reflective surface; somewhat less ductile because of cold work.
No. 4	Standard Polished.	Bright polished surface.
No. 6	Standard Polish, Tampico Brushed.	Velvety appearance from dimming No. 4.
No. 7	High-luster Polish.	Extensively polished and buffed to near-mirror finish.

The finishes are available on one or both sides of the sheet.

Nickel-base sheets come in four standard finishes:

1. Hot rolled.
2. Hot rolled and pickled.
3. Cold rolled.
4. No. 9—Satin finish equivalent to a 180 Grit Finish (No. 4 Finish is 120-150 Grit Finish).

Strip

A rolled product less than 24″ wide, whose thickness may vary from 3/16″ down to 0.005″ or less is called *strip*. Strip finishes are commonly:

1. Cold rolled, annealed and pickled.
2. Same as 1, with re-rolling.

Linings and Clad Steels

A further breakdown of available forms of plate material would include field applied linings, shop applied linings, and clad steels. These are combinations of carbon steel plate with a corrosion-resistant alloy.

Field Applied Linings—Of all the methods of applying linings, application in the field is the most costly for the following reasons:

1. It is necessary to scaffold the I.D. of the entire vessel.
2. It is necessary to thoroughly clean the inside of the vessel by sandblasting.
3. To aid in handling and fit-up, lining sheet should not exceed approximately 40″ in length and, in digester application, shauld not exceed 3″ to 3½″ in width unless clad lining plate is used.
4. The majority of the welds will be made in the horizontal, vertical, or overhead positions in which welding is slower and more apt to produce inferior welds than that done in a flat position. Due to the small size of the liner sheets, a considerable amount of welding must be done.
5. Testing of the quality of attaching welds for the possibility of leaks is almost prohibitive due to the large number of liner sheets applied.
6. Stress relieving after field lining is prohibitive due to the high cost of insulating the vessel and heating it.

A description of the more common methods of field lining of vessels is now given.

Figure 9—Strip lining with a straight butt joint. This type of lining is perhaps the most commonly used and is one of the cheapest to apply. It is normal practice to space the plates approximately ⅜″ apart and to weld a fillet to each of the liner plates and then apply a cover pass over the unwelded section in the center and the two fillets. Alloy content of the electrodes is higher than that found in the liner plate to overcome dilution. Clad steel has been used for field lining, of ⅜″ thickness, and is welded in with straight butt joints. The small differences in the physical properties of the carbon steel shell and the carbon steel backing tend to overcome a lot of the difficulties experienced in using a solid light-gauge metal for the lnier.

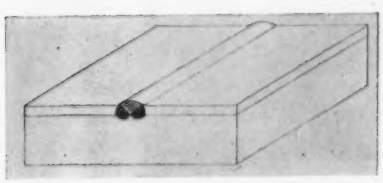

Figure 9—Strip lining with straight butt joint.

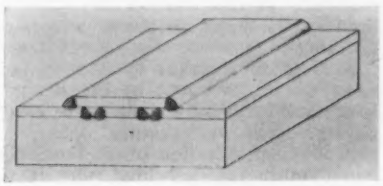

Figure 10—Butt straps over strip lining.

Figure 10 — Butt straps over strip lining. This type of construction is used in corrosive service where it is desired to provide an additional protection over the joints. This type of construction is expensive and difficulty is experienced in producing satisfactory fillet welds between the liner sheet and the cover plate, as high stresses are present in this type of joint and cracking is often found.

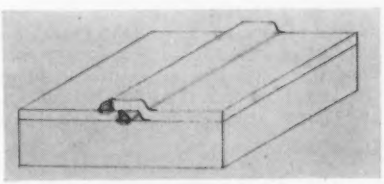

Figure 11—Joggle—or lap—type construction.

Figure 11 — Joggle- or lap-type construction. This type of construction offers good corrosion resistance but is extremely expensive and difficult to fit up.

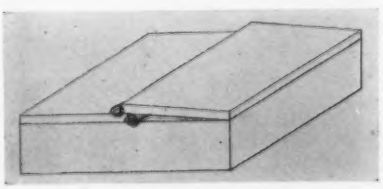

Figure 12—Shingle-type construction.

Figure 12—Shingle-type. This type of construction is difficult to fit up.

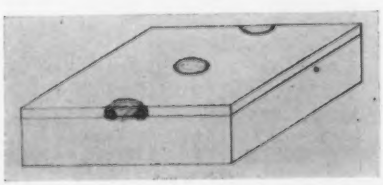

Figure 13—Plug welds.

Figure 13—Plug welds. These welds are normally made on 3″ x 3″ staggered centers using a ½″ min. diameter chamfered hole. This is very difficult to apply from the standpoint of the welding, as a weld must be made through 360° around the perimeter of the hole.

Shop Applied Linings

Shop applied linings, as the name suggests, are handled in the fabricating shop. The three common methods use sheets up to 48″ wide and 144″ long. The welding is done in the flat position prior to forming the sheets. The lining for digesters must comply with the requirements of Case 1078 of the ASME Boiler Construction Code.

The first method is by *seam welding*, and is illustrated in *Figure 14*. Plates

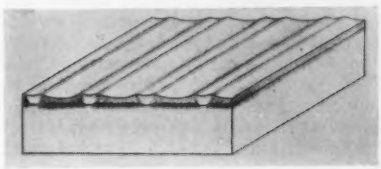

Figure 14—Seam welding.

are manufactured by the use of overlapping seam welds in the longitudinal direction. These welds do not overlap on the transverse direction but leave a small section of the alloy liner material that is not welded to the backing plates. This material is the nearest approach of any to the homogeneously bonded clads and can only be criticized for its extremely rough surface due to the pressure exerted by the seam welding wheel. This material is generally applied in thicknesses averaging 7/64″.

The second method is by *spot welding*. This type of lining is illustrated in *Figure 15* and consists of spot welds on various centers, such as 1″ x 1″ or 3″ x 3″, depending on the application. It can be applied in gauges up

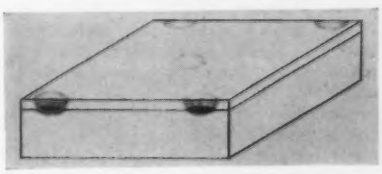

Figure 15—Spot welding.

to 3/16″ thick but is most commonly used in 5/64″ or 7/64″ thicknesses.

The third method of shop applied

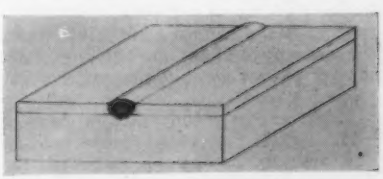

Figure 16—Through welding.

linings is by means of *through weld-*

ing. This type of lining is illustrated in *Figure 16* and is generally made by taking a large liner sheet and welding through it and into the backing steel with an automatic welding machine. These welds are spaced on centers of 3″ and up, depending on the application. Dilution of the weld metal is compensated for by using a higher alloy electrode.

Clad Steels

Clad steel is a composite plate made up of a carbon or low-alloy steel backing plate, to one or both surfaces of which is uniformly and inseparably bonded over the entire surface, a cladding of some corrosion-resistant metal. The percentages of cladding normally supplied are 10% and 20% of the composite thickness of the material. Other percentages of cladding can be supplied on request. The use of the full thickness of the clad material in design is permitted under Case 896 of the ASME Boiler Construction Code. This case coupled with the ASTM Specification A-263 (chromium steel cladding), A-264 (chrome-nickel steel cladding), and A-265 (nickel and nickel-base alloy cladding), requires that the clad materials exhibit shear strength in excess of 20,000 psi.

These clad materials are easily formed and fabricated into finished structures using established procedures. Bend tests of as-welded samples more than meet the requirements of the ASME Code, Para. U-200, even in the as-welded and unstress-relieved conditions. The clad surface is smooth and uniform. *(See Figure 17)*

Liners, in general, with the exception of seam welded liners, shown in *Figure 14,* all are characterized by large unbonded areas between the attaching welds. The attaching welds hold the liner plates at the points of attachment and restrict their movements at those points to that of the base plate. The rate of thermal expansion of austenitic stainless steel liner plates is approximately 50% higher than that of the steel base plate. Because of this, if the spacing of the attaching welds is wide, buckling or bulging of the liner will take place. This buckling may be elastic at wider spacings or may produce plastic flow at narrower spacings. If the attaching weld spacings are very close, elastic compression followed by plastic flow will take place. This produces, in all cases, a highly localized concentration of stresses at the liner plate adjacent to the attaching welds. In cyclic temperature operation, such as the heating and cooling experienced in the cooking of pulp, this concentration of stresses may cause failure of the liner plate, or of the backing plate, in any one or combination of the following ways:

1. Stress corrosion cracking, due to high tensile stresses, causes plastic deformation in the presence of the proper electrolytic solution. Recent examples and service failures of lined sulfate digesters due to stress corrosion cracking have shown that the concentrated cooking liquors, coupled with high stresses, will produce this type of failure. Sulfite digesters have also failed from this cause.

In contrast to this, when a clad plate is rolled up and welded, the cladding alloy on the inside of the vessel is stressed in compression. Additional compressive stresses are introduced into the cladding by any operation that raises the temperature of the vessel. This point is extremely important, as materials in compression have never been known to cause stress corrosion cracking.

2. Mechanical cracking due to fatigue failure produced by the flexing back and forth of the liner material during cyclic temperature operation may allow penetration of the cooking liquor in digesters behind the liner. Here it is concentrated due to evaporation, and general attack may take place on the base metal or the liner.

In the above two cases, where a digester liner is definitely penetrated, a concentration cell may be set up and galvanic attack of the carbon steel can take place. In addition to this, due to the reducing condition, stainless liners may lose their passivity and become subject to corrosion by pitting, general attack or intergranular corrosion. Also, stress corrosion may occur at or near the welds and the liner will open up and separate from the backing steel.

When a digester lining has cracked, as in (1) or (2) above, the extent of damage is wide-spread because the unbonded, unattached areas of the liner sheets extend to a considerable extent, and large area of backing steel are exposed, such as shown in *Figure 15.*

3. Localized general attack may take place in liner plates due to the large amount of welding lowering the corrosion resistance by dilution of the liner. Proper metal selection can prevent this.

Consideration is given in the design of lined digester to a corrosion allowance of steel of ⅛″ or more on the head, shell, and on the cone bottom, in addition to the liner plates. This extra steel is added as a precaution in the event of liner failure. In the case of clad steel digesters where stress corrosion cracking or fatigue failure of the lining is not a factor, this extra protection can be eliminated with the resultant savings in material.

It is normal fabricating procedure to X-ray, at the same time, both the weld in the steel side and the alloy side of the clad plate. This insures that the weld is free from cracks or other defects and that corrosion-resistant properties are maintained. When lined vessels are X-rayed, the liner welds are only X-rayed when they cross the vessel's main seams. Therefore, to insure that all liner welds are sound, each panel of the liner must be hydrostatically tested.

The surface of the clad steel plate is free of depressions and offers resistance to the crevice corrosion that is often found on rough surfaces. This smooth surface is also an aid to pulp removal in digester service.

In addition to the factors just covered, the initial cost of the material has a bearing on the selection of the proper form of corrosion-resistant

Figure 17—Photograph of Specimen Panel showing Clad Steel test specimens, welded plates and sodium hydride finish.

metal. In solid form, the cost of stainless steels is directly dependent upon the chromium and other alloy content. This is not always true of the clad forms. Wall thickness of a vessel gives a handy guide for proper selection.

When the wall thickness is 3/16" or under, solid alloy is usually most economical. From 3/16" to ½" solid material and clad material are competitive. If consideration is given only to the higher allowable stresses permitted in the solid material, it is generally most economical in gauges from 3/16" to ½". However, the majority of applications for clad steels under 5/16" gauge in the past have been storage tanks, processing tanks, and other types of vessels where stiffness or rigidity, more than tensile strength, is the governing factor in design. There are additional factors, often overlooked, that apply to design of pressure vessels in gauges of ½" down to 3/16". They are:

1. The use of higher tensile backing steels, such as A-212 or A-204, reduces the difference between the allowable stresses of the clad and of the solid materials. However, high temperature applications give the chrome-nickel stainless steels and Inconel in solid form a definite advantage over clad, while the straight chromium steels and Monel and nickel in the solid form are at a disadvantage under these conditions. This is due to the higher allowable stresses at elevated temperatures for the chrome-nickel steels and Inconel. If heat transfer only is considered, clad has a definite advantage over chrome-nickel steels, straight chromium steels, Monel and Inconel in the solid form, due to better heat conductivity of these metals in clad form.

2. The overweight tolerances for solid materials are somewhat in excess of that for clads. This could be quite important if a large vessel is under consideration.

3. Hot forming costs for solid materials are considerably higher than those for clad. In addition to these costs, annealing and pickling are not included in the base price for solid materials while they are included in the base price for clad materials. Here again this could be quite important if a large vessel is under consideration.

4. It can be readily seen that in gauges under ½", the fabricating cost of the two forms of material will vary due to the design, and no definite general advantage can be given to either form. Each case must be considered individually.

From ½" to 1¼" wall thickness, clad and lined material are very competitive. Above 1¼", lined is usually most economical if operating conditions permit its use. As pointed out above, for many types of applications linings cannot be used, since consideration must be given to such factors as surface, heat conductivity, and differential expansion with resultant high stresses and possible stress corrosion cracking under cyclical temperature application.

If severely corrosive conditions require a heavy gauge (⅝" and up) of corrosion-resistant material, a change in material is indicated. Heavy gauges of solid stainless steels and Inconel in general are used because of the higher allowable stress permitted at high temperature (above 650° F.) and not because of severely corrosive conditions.

Plating

While the cost of chromium plating is not low, in a number of instances, it has been found to be the cheapest way of preventing corrosion. Pure chromium has a bright appearance, excellent heat transfer properties and exceptional wear and corrosion resistance, all of which are points to be considered in connection with its use. Nickel plating does not have the hardness of chromium plating but finds wide use for its corrosion resistance and appearance.

PART III

Applications

This part discusses specific applications of corrosion-resistant metals in the pulp and paper industry. Pulp manufacture and bleaching are the normal places where severe corrosion problems exist. Local conditions may give rise to other critical places. At the other points, mild corrosion, product contamination, or ease of clean-up are the main problems. This part is set up in outline form, listing only those items where corrosion-resistant metals have been used, with pertinent comments where necessary.

1. Pulp Manufacture (general)

A. *Digesters*—Corrosive attack may be especially severe at the liquor level line, in the vapor section, in the cone section, and at the inlet and outlet nozzle areas where condensation or erosion are more pronounced. Corrosion of carbon steel digesters has been accelerated in recent years, and the reasons below may help to explain why.

(1) In the past, the majority of digesters were built from low tensile rimming steels. This material has a rim on each side of the plate of almost pure iron and was normally supplied with low tensile strengths. It is considered that this rim has better corrosion resistance than that found in the killed or semi-killed steels which have been used recently. These killed or semi-killed steels contain silicon which is believed to reduce resistance to corrosion. In addition to this factor, it is possible that the higher tensile strength materials inherently will corrode more readily than those displaying low tensile strengths, probably in connection with incipient stress corrosion.

(2) The pulp industry, in general, is going to higher temperatures and pressures which will influence the rate of corrosion detrimentally.

(3) Stronger solutions are now being used in the cooking liquors which again detrimentally effect the corrosion rate.

(4) Increased circulation is often being used, which increases the chance of erosion and aeration. Increased aeration may accelerate corrosion, though not on stainless steel, and erosion is tied in with the destruction of a passive film on the metal.

(5) In many areas, mill have started to add a certain percentage of hard woods to their charge, due to the decreasing availability, with consequent increase of cost, of the soft woods normally used. This factor produces modifications in the theoretical basic cook.

(6) At the same time, some mills have felt it desirable to shorten cooking time for economical reasons; and one method of doing this is the use of accelerators or wetting agents, which again cause chemical modifications in the basic cook. (See specific recommendations under sulfate, sulfite and soda pulps.)

2. Groundwood Pulp

A. *Grinder Pit Liners*—Mild corrosion and strong erosion. Type 304 solid stainless plates have been used to combat such attacks. Clad or lined could be used.

B. *Pulp Stone Flanges*—18-8 stainless castings have been used.

C. *Stock Lines*—18-8 stainless and Monel, either in cast, solid, clad, or lined form, may be used. Ease of clean-up is the big factor here.

D. *Multistage Washers*—Monel or 18-8 stainless steel sheet, clad or lined plate may be used.

E. *Unbleached Pulp Chest*—Usual construction is concrete or tile-lined pit. 18-8 stainless-clad or lined plate could be used.

F. *Hydrogen Peroxide Storage* — Aluminum drums or tanks should be used.

G. *Peroxide Bleach Dissolving Tank* —May be made of aluminum or 18-8 stainless-clad or lined plate.

H. *Peroxide Bleach Head Tank* — Same as "G."

I. *Mixer*—18-8 stainless steel clad or lined plate.

J. *Bleaching Tank*—Type 316 stainless-clad or lined plate will stand up in this service.

K. *Bleached Stock Chest* — Lead, copper, or iron are no good. Lead and copper are active catalysts for peroxide decomposition. Iron is also a catalyst, though not as active. Any type of stainless steel or nickel-base clad or lined plate will be adaptable.

3. Sulphate Pulp

A. *Chip Screens*—See 3-A.

B. *Digesters* — Inconel and Types 304, 316, 316 E.L.C., 316 Cb, 317, 347, 405, and 410 stainless steels in clad or lined form have all been used. Experience with Types 405 and 410 has not been sufficient to be conclusive. Failures of lined digesters with the various types of stainless can probably be attributed to factors discussed in

Part II. Inconel is used because it is not subject to caustic embrittlement.

C. *Turpentine Recovery* — Nickel, 18-8 stainless, or Everdur bronze castings, sheet and clad or lined plate are used.

D. *Diffuser Cyclone* — Steam and caustic in the presence of air cause trouble here. Type 304 stainless-clad has been used successfully.

E. *Multistage Washers* — Monel or Types 304, 316 and 347 stainless are used for built up decks and facings. Ni-resist is good for cast parts.

F. *Evaporators*—18-8 stainless-clad or lined shells; 18-8 stainless tubes; tubes chrome plated on the outside to reduce sulfide corrosion; Inconel tubes; 18-8 stainless-clad tube sheet; and Whorthite or Durimet 20 (special austenitic stainless steels) in transfer pumps. Inconel tubes are apt to be expensive. For multiple-effect evaporators, the following chart is useful:

Effect	Shell	Tube Sheet	Tubes
1	a	a	a
2	a or b	a	a
3	a or b	a or b	a or b
4	b	b	b
5	b	b	b

Note: a = Types 304, 316, or 347 stainless.
b = Carbon Steel.

G. *Tall Oil Soap Making* — In the batch process, Monel is suitable for sulfuric acid fat splitting. The 18-8 stainless steels, nickel and high nickel alloy steels are used in other places.

H. *Recovery Stacks (Fume Stacks on Smelters)* — No economical known metallic substance will stand up for this service, especially in the area where moisture will condense.

I. *Smelter Spouts*—Type 309 or 310 stainless.

J. *Green Liquor Storage Tank* — Monel, nickel, or 18-8 stainless or clad steels may be used.

K. *Slaker*—Type 304 stainless steel. Monel is better if dilute hydrochloric acid is used in lime sludge filters.

L. *Causticizing Tank*—A well known equipment manufacturer is said to prefer Type 304 stainless steel to carbon steel here.

4. Sulfite Pulp

A. *Chip Screens* — Abrasion resistance is a big factor here. Heavy gauge stainless steel wire is used.

B. *SO_2 Cooler* — Type 316 or 317 stainless steel clad or lined plate are used in the spray type; lead, in the submerged type.

C. *Acid Tower* — Type 316 or 317 stainless steel clad or lined plate.

D. *Absorption Tower* — Wood, lead, or concrete with tile lining.

E. *Acid Storage Tank* — Type 347 stainless is good only if the acid is cold. Type 316 may be used if it is annealed (may be subject to intergranular corrosion if it is not). Type 316 E.L.C. is also used. May be solid, clad, or lined.

F. *Accumulator*—Type 316 or 317 clad or lined.

G. *Digesters* — Stainless-clad or lined plates compete successfully and economically with ceramic linings. Type 347 is of doubtful value in the presence of SO_3, unless it is cold. Types 316 Cb and 316 E.L.C. may be used for neutral sulfite semi-chemical pulping or 304 for continuous pulping. Type 316 E.L.C. or Cb stabilized may be used for a regular sulfite cook. Type 316 may be used for magnesium or ammonium soluble base cooks. The use of Types 405 and 410 is still experimental.

H. *Blow Lines*—Type 316 stainless-clad, solid or cast. Also cast iron, bronze or Ni-resist may be used.

I. *Blow Pit or Tank* — Type 316 stainless in solid, clad, or lined form. Target plates should be solid. Nozzles and false bottom may be solid or other forms.

J. *Gas Recovery* — Sulfite waste liquor recovery and utilization requires Type 316 stainless in solid, clad, or lined form for the alcohol plant equipment.

K. *Fume and Vomit Stacks*—Normally wood or tile. Type 316 stainless would be all right only above the temperature where condensation begins.

L. *Multistage Washers*—18-8 stainless sheet or clad steel plate may be used.

M. *Knotters* — 18-8 stainless or Monel wire may be used. Also punched or slotted sheets.

N. *Riffler*—Usually tile. Types 316 and 347 stainless sheet would give smoother surface. Monel an dbronze or steel chromium plated could also be used.

O. *Fine Screens*—Usually brass or bronze plate. Type 304 or 316 stainless, Monel, or Inconel sheet may be used, but rigidity is a factor. These same materials in clad form could be used, but carbon backing steel needs protection. These materials maintain slot width longer than brass or bronze.

P. *Course Screens* — Same as fine screens.

Q. *Thickener or Decker*—Type 304 or 316 stainless, nickel, and Monel are used for channels, winding wires, backing wires, facing wires, and binding wires or straps.

R. *Unbleached Pulp Stock Chest*—Type 316 stainless, Monel, or Nickel sheet, clad or lined could be used.

S. *Peroxide Bleach* — See under Groundwood Pulp.

T. *Chlorine Washer* — Type 316 stainless sheet used for washer covers.

U. *Caustic Bleach*—Nickel plate or clad should be used with caustic.

V. *Caustic Washer*—Nickel, Monel, or 18-8 stainless steel sheet for covers and plate for vats.

W. *Hypochlorite Bleach*—Monel is satisfactory for calcium base; may fail with sodium base. Calcium builds up an insoluble protective scale, while the sodium reaction give soluble products. Type 316 stainless might be satisfactory in a batch system where exposure would be for a manimum time.

X. *Hypochlorite Washer*—Monel or 18-8 stainless sheet for covers. Unless solution is Cl_2 free, Types 316 or 317 are the only suitable 18-8 stainless steels.

Y. *Thickeners*—Monel sheet covers.

5. Soda Pulp

A. *Digesters*—Usually carbon steel. A 20 percent Lukens Inconel-Clad Steel plate is going to be installed in the middle course of a soda digester at the Great Works, Maine, plant of Penobscot Chemical Fiber Company this summer. This is being installed to combat severe erosion at the liquor line. This erosion may have been accelerated by stray electrical currents. Such use of Inconel will permit a switch to kraft at a later date if desired. Monel has been used extensively for pipe in circulating systems, blow-off valves, and white liquor valves.

B. *Wash Pans*—Monel lined, stainless-clad or nickel-clad plates are used.

C. *Diffusers*—Same as 3-D.

6. Stock Preparation

A. *Pulper* — Nickel-clad and 18-8 stainless-clad are used in hydrapulpers. Solid 18-8 stainless plate and castings are used in E. D. Jones Pulpmasters. Solid 18-8 stainless is used in the Cowles hydrafiner.

B. *Beaters*—Erosion, ease of wash-up, and stock contamination are factors here. 18-8 stainless sheet and solid, clad, or lined plate are used here. Tile lining, or copper lined wood are also used. Monel or "K" Monel are used for beater bars.

C. *Jordans or Refiners*—Monel "K" Monel, and Type 302 stainless have been used very successfully for Jordan fillings and bars. These materials maintain their sharp edges for long periods with considerable savings in care necessary to produce uniform stock preparation.

7. Fourdrinier Machine

A. *Screens*—Monel, Inconel, and 18-8 stainless screen plates. Bronze was used, but had poor slot wear. Chromium plated bronze was also tried, but the plating flaked off.

B. *Flow Box, Head Box, and Slice* —Here ease of wash-up and slime control are big factors. Bacteria will lodge on a rough surface. Slime is produced by anaerobic (living or acting in the absence of free oxygen) bacteria, which are iron feeding and which give off acid in the course of living that will corrode an iron surface. Copper will kill them, but is soft and apt to erode. Stainless steel, nickel, and Inconel provide a less adhesive surface and are corrosion-resistant. Monel or Type 316 are useful if brackish water is apt to be used. They are all available in economical clad forms. All of these metal surfaces are highly abrasion-resistant, and will not chip, peel, crack, or spall. A highly polished surface, (such as No. 4, Luster, or Super Luster) smooth joints and contours and lack of blind corners are more important than type of corrosion-resistant material. If a corrosion-resistant metal is used, the pH can be lowered somewhat to help alum sizing.

C. *Distributor Roll*—Monel or 18-8 stainless are used.

D. *Flow Spreader*—See 7-B.

E. *Shower Pipes and Nozzles* — Monel or 18-8 stainless are used.

F. *Breast Roll* — Bronze or Monel covered steel or iron.

G. *White Water Pans and Trays*—Monel or 18-8 stainless sheet.

H. *Save-all*—Monel or 18-8 stainless sheet and solid, lined, or clad plate may be used.

I. *Suction Boxes* — Monel or 18-8 stainless solid, lined, or clad plate and castings may be used.

J. *Fourdrinier Frames* — Monel or 18-8 stainless solid or clad plate, or Monel or 18-8 stainless sheet lining over carbon steel or iron.

K. *Table Rolls* — Aluminum, brass, 18-8 stainless, or Monel tubing or pipe.

L. *Dandy Roll* — Monel body and cover wire.

M. *Press White Water System*—See 7-G.

N. *Broke Beater*—See 6-B.

8. CYLINDER MACHINE

A. *Regulating Box*—Monel or 18-8 stainless sheet and solid, lined, or clad plate.

B. *Head Boxes*—See 7-B.

C. *Vats*—See 7-B. Ease of clean-up is particularly important on job lot runs. Type 316 stainless or Monel in solid or clad form should be used if brackish water is apt to be encountered, as Type 302 has been known to fail prematurely under these conditions.

D. *Molds* — Nickel, Monel or 18-8 stainless wire and rod may be used.

9. COATING AND SIZING

A. *Size Making Tank* — Lukens Nickel-Clad Steel plate has been used to prevent discoloration.

B. *Size Press Pans*—Monel Sheet.

C. *Alum Tanks*—Monel is used.

This ends the list of specific applications in the pulp and paper industry. One of the prime reasons for using corrosion-resistant metals in places where extreme corrosive conditions do not require their use was summed up by a paper mill superintendent, who said, "We have problems enough in making paper, so we are very happy if we can install equipment and then forget it."

In concluding, it should be stressed once more that each corrosion problem requires individual study to be sure that all pertinent factors have been taken into consideration. The suppliers, fabricators, and customers, working as a team, will find new and increasingly economical uses for corrosion-resistant metals, with a resultant economy of production.

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Applications of Chemical Engineering To Pulp and Paper Technology

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Introduction

It might seem that a discussion of this subject could well start with the question "What is Chemical Engineering?" I do not expect to answer this question to the satisfaction of all chemical engineers. It is hoped, however, that the following statements may help you to understand the reasons for my interest in this topic.

Chemical engineering, as now practiced, was not heard of until centuries after the art of papermaking was introduced. In fact, it is the youngest of the branches of engineering that are commonly recognized today. The American Institute of Chemical Engineers will celebrate its fiftieth anniversary in 1958. Contrast this fact with the invention of the Fourdrinier paper machine attributed to Louis Robert in the year 1799 and the invention of the cylinder paper machine, by John Dickinson in 1809. Furthermore, instruction in the phases of chemical engineering, as now conceived, was initiated in only a few of our American universities and colleges prior to 1930. Previous to that time the so-called chemical engineer was trained in theoretical and industrial chemistry, mathematics and to some extent in electrical and mechanical engineering as such.

Since 1930, due largely to the pioneering efforts of Warren K. Lewis and Walter L. Badger, many of our American schools have modified their chemical engineering curricula to approach the objectives described by George G. Brown *(1)* in his book "Unit Operations" published in 1950. Brown claims that the following four concepts are basic to, and form the foundation for the calculation, of all operations:

(1) The material balance—as defined by the first law of thermodynamics.

(2) The energy balance—as illustrated by the second law of thermodynamics.

(3) The ideal contact—as related to an approach to equilibrium, the latter being of either a physical or chemical nature.

(4) Rates of an operation—these also applying to either a physical or chemical action.

The so-called unit operations have been utilized as a means of studying these four concepts and applying them

to the design and operation of industrial plants. There has been little agreement with regard to the number of unit operations or what constitutes a unit operation. Perry, *(2)* in the revised Third Edition of Chemical Engineer's Handbook, lists about ten such operations. Although Brown does not tabulate them as such he indicates over fifteen similar operations. In the opinion of the writer the more useful of these operations are Flow of Fluids, Heat Transfer, Evaporation, Distillation, Extraction, Gas Absorption, Filtration, Humidification and Drying. Other operations could be listed such as Size Reduction, Adsorption, Sedimentation, etc. It is also recognized that these operations may, or may not, be accompanied by the transfer of appreciable quantities of matter as in the cases of Distillation, Gas Absorption and Humidification. Consideration is now being given to grouping several of these operations under the heading of Mass Transfer.

In any event, Brown summarizes the situation well with the statement, in reference to the four concepts, "These principles, used singly or in combination, and the co-ordinated knowledge of the unit operations . . . constitute the science or theory of the unit operations. Practical engineering consists in applying the understanding of these operations and practical knowledge of the many types of equipment that may be employed to the design and operation of a commercial plant that will show not only a material balance but also a favorable dollar balance."

Application to Pulp and Paper Technology

It is our contention that these principles apply as generally, and as rigorously, to operations incidental to the production of paper as to any other material. The limited time for this presentation will not permit an exhaustive enumeration of the application of each principle and unit operation to the various phases of pulp and paper making. It is proposed, therefore, to list a few of the phases of the industry and indicate the principles and operations pertinent to them.

Production of Pulp. Wood Room. An accounting of wood, by a material balance with regard to usable chips, bark, and sawdust is essential to the economy of that operation and a more detailed explanation appears in the lecture presented by Lewis. If a stream barker is used the principles of flow of fluids are utilized and if a waste heat boiler is used its effectiveness should be investigated by energy balances.

Flow of Pulp Stock. The manufacture of paper from pulp stock of approximately one percent consistency, and the transportation of stock at higher consistencies during its processing, presents a variety of problems of a hydraulic nature. Some data exist on the head loss due to friction during the flow of pulp stock in pipes. The most detailed, and more recent, data on this subject are presented by Brecht and Heller *(3)*. The data as a whole are not in good agreement, however, and the Technical Association of the Pulp and Paper Industry has had a committee on Hydraulics which has stressed for several years the desirability of improving and extending these data. This fact illustrates the importance of flow of fluids as an operation to the pulp and paper industry.

Acid Making. The combustion of sulfur, including its preheating and melting, involves heat transfer, material and energy balances, the approach toward several chemical equilibria and certainly the rate of physical and chemical reactions. Cooling of the burner gases may involve indirect heat transfer or, in the case of a spray cooler, direct heat transfer, mass transfer and again an approach toward chemical equilibrium. The equilibrium referred to is, of course, that between sulfur dioxide and sulfur trioxide.

Sulfur dioxide is then absorbed from the cooled gas in some kind of absorption equipment. If an alkali base is utilized, this operation constitutes a complex type of gas absorption in that chemical reaction will accompany the physical absorption. The principles of gas absorption nevertheless apply and the equipment may be designed and operated consistent with the necessary driving forces to accomplish the desired operation.

You might well ask "How was this accomplished as an art before the science of gas absorption was developed?" My answer is that it was so developed, largely for calcium base sulfite acid, by plant or pilot plant experience. It would seem to follow, then, that if a change of base is made the same tedious procedure would be necessary unless advantage can be taken of the principles of gas absorption. The Crown-Zellerback Corporation *(4)* has recently constructed an experimental absorption tower to study the recovery of sulfur dioxide in ammonia base sulfite liquor which was designed on the basis of gas absorption coefficients.

Raw acid is converted to cooking acid by fortifying further with sulfur dioxide, released from digesters, by the process of absorption in accumulators. Admittedly, there is little known at present regarding the rate of gas absorption as an operation in this type of equipment in which gas is bubbled into liquid. Data exist, however, for the partial pressure of sulfur dioxide over acid solutions at elevated temperatures and the principles of gas abtorption can be taken advantage of at least qualitatively.

Digestion. Energy considerations, material balances, the approach toward equilibrium and certainly the rate of reactions are exemplified in the digester. If outside circulation of liquor and indirect heat are employed, these constitute specific illustrations of flow of fluids and heat transfer combined.

Pulp Washing. As conventionally done, this operation takes particular advantage of the principles of filtration and extraction. If the pulp has resulted from an alkaline cook, the extract liquor is then evaporated and subsequently burned. Many types of multiple effect evaporators are used for concentration of the liquor extract before it is burned. They all employ indirect transfer of heat and long tube, vertical evaporators are in common use now.

Recovery of heat from the solids content of these liquors involves all the principles incident to a steam generation unit in addition to the operations of evaporation and humidification, with particular application of the latter to disc evaporators. If chemicals are recovered from alkaline waste liquors, conventional practice also includes the operation of counter current extraction, as illustrated by the recovery of sodium hydroxide from calcium carbonate sludge. Chemical recovery also involves vacuum filtration and calcining.

Bleaching. Bleaching is essentially an extraction operation. It may involve the principles of gas absorption in the preparation of bleach liquor. In any event the success of the bleaching operation depends upon an approach to equilibrium and the rate of several reactions of both a physical and chemical nature, which must be controlled in operation by the use of material balances.

One could doubtless mention many other direct applications of the unit operations to the production of pulp for paper making purposes. Let us consider, however, the production of a sheet of paper.

Economic Balance. As Brown has stated the commercial operation as a whole must show a favorable dollar balance. In order for the plant to operate at the most favorable profit each individual operation must be conducted at minimum cost or maximum profit. These conditions of operation are best found by applying the principles of chemical engineering to each operation.

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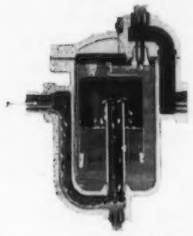

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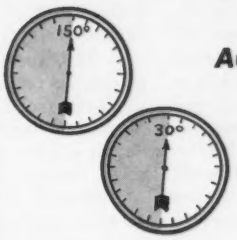

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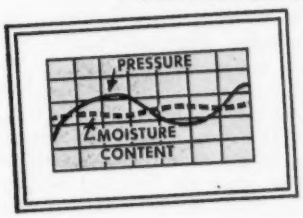

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nomic balance to the wood room has already been mentioned. It can be applied to any other operation, or piece of equipment, and may involve any combination of Brown's four concepts. Suppose we consider one illustration each of an operation to be conducted at minimum cost and maximum profit.

Evaporation of black liquor, in itself, is an out-of-pocket expense. It should be conducted at minimum cost. The major costs of this operation are primary steam, labor and fixed charges on the equipment. The amount of steam required can be computed by the principles of heat transfer and depends upon the number of effects of the evaporator. Fixed charges also depend upon the number of effects and type of construction. Labor costs are virtually constant. The optimum number of effects should be selected that corresponds to the lowest total cost of steam and fixed charges.

The recovery of black liquor by washing pulp is a good illustration of an operation that should be done at maximum profit. The black liquor has a definite value as a source of heat and chemicals. It costs a certain amount, however, to perform the extraction, evaporation and subsequent operations. If too much wash water is used the cost of evaporation might exceed the value of the chemicals and solids that would be recovered. On the other hand, if too little wash water is used the amount of chemicals and solids recovered is limited by the rate of extraction. It follows, therefore, that the optimum amount of wash water is that quantity which allows the *difference* between the value of the products and cost of getting the products to be a maximum.

Paper Making. Introduction of pulp stock to the wire certainly involves many aspects of the flow of fluids. Although pulp stock is a non-Newtonian fluid, the principles of the flow of fluids apply to its passage through conduits, the head box itself, and the slice in a manner similar to that of other orifices. At present there is little agreement, and much that is not understood, with regard to the thermodynamic properties of pulp stock as related to the flow of fluids, nevertheless, the general principles apply and application of them may result in increased efficiency of pulp stock handling.

Wires. The drainage of water from stock on a Fourdrinier wire is essentially a matter of filtration of water through a mat of pulp. Admittedly, little is established regarding the relationships of driving force to the rate of filtration of any material. It seems reasonable to predict, however, that a continued study of drainage rates, from the standpoint of filtration, will eventually, increase the efficiency of that operation. It is known, for instance, that in recent years the overall length of the wet end of some paper machines has been materially reduced for the same, or even higher, machine speeds. In order to accomplish this effect, the rate of filtration of water must have been increased by some means, the suction breast roll being an example.

Felts. Although wet felts are used primarily to carry the sheet through the press sections to facilitate the removal of water by pressure, they also act as a filter medium in so doing. In their passage over a suction box or suction roll, the same principles apply as those that apply to the vacuum filtration of any material.

Drying. The drying of a sheet of paper is accomplished by balancing a rate of transfer of heat to satisfy a rate of drying of the sheet itself.

Other things being equal, a sheet of paper tends to dry at a constant rate when sufficiently wet and at a continually decreasing rate as it approaches dryness. This fact, coupled with varying conditions of humidity throughout the dryer section, causes variable rates of drying from one cylinder to another.

The necessary latent and sensible heat to provide drying is transferred through the cylinder wall. In its passage through the wall it first passes through a film of condensed steam and finally through an air film, and possibly a felt, to the sheet of paper. These media constitute a series of resistances to the transfer of heat. The sum of the resistances and the temperature drop across them determine the amount of heat that will be transferred per unit area in a given length of time. If these values are known sufficiently accurately, and the drying rates are also known under the variable conditions, one could calculate the amount of heat transfer area needed to dry a sheet of paper at a given overall rate.

Unfortunately, this is seldom the case. Although many overall results of mill drying have been reported, comparatively little data are published on either the rates of drying under specified conditions or an individual resistances to heat transfer. Much has been accomplished by engineers, however, by taking advantage at least qualitatively, of the principles of heat transfer, drying and humidification that are simultaneously involved.

For instance, the resistance of the metal wall itself is kept to a minimum within the limits of safety and durability. The so-called "rimming" dryers supposedly reduce the resistance to heat transfer inside the cylinder. The judicious use of dryer felts may reduce the resistance to heat transfer between the cylinder and the sheet. Finally the forced passage of warm air throughout the dryer section, and the use of exhaust hoods, can be economically effective in increasing the drying rate of the sheet.

Other citations of the application of unit operations and fundamental concepts to the production of pulp and paper could no doubt be made. It is hoped, however, that these are sufficient to support the claim that they can be applied as generally to the pulp and paper process as to any other industry.

Conclusion

An attempt has been made to indicate the potential value of a knowledge of the fundamental concepts and unit operations of chemical engineering to the production of pulp and paper. Attention is again called to the value of this approach to both the design and operation of commercial equipment.

It is recognized that in utilizing this approach we must distinguish carefully between those principles that are never controverted and empirical relationships that hold only for a given set of conditions. For instance, although we all recognize that "heat will not flow uphill," it is not uncommon for a negative driving force to exist in cases of attempted gas absorption or drying. By the same token, a rate of drying that has been measured under certain drying conditions may not hold at all for certain other areas of a dryer section.

It is to be emphasized that theoretical knowledge alone, no matter how good, is seldom effective from the standpoint of the dollar material balance. Advantage must be taken of technical skills and consideration must be made of the manifold demands on the process that are imposed by production methods and by personnel relationships.

Nevertheless, this constitutes a plea for the continuation and extension of carefully planned fundamental research that may eventually allow a more effective utilization of the principles of chemical engineering in the production of pulp and paper.

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Paper Section

Waste Paper, Its Collection and Usage

J. A. Benedetto

and

Robert A. Graham

Mr. Benedetto is president of D. Benedetto, Inc. and subsidiary companies in the United States, Canada and the Continent. He has spent his entire life in the Waste Paper business. Mr. Graham has been connected with the waste paper industry since early boyhood, and since early manhood has always had an executive position with the company with which he was associated. His original employment was with P. H. Graham & Sons Co., Inc., which company, in 1935, was succeeded by The Graham Corp. of which he has always been treasurer and general manager.

We are here to talk about waste paper, so-called waste paper. It really is not waste paper at all, unless you waste it. It is actually prime raw material in the wrong place. Its right place is in the beaters and hydrapulpers of the paper and box board mills where the fiber in it can be converted into paper and box board.

Because this fiber, originally in a tree, never dies unless it is destroyed by fire or by other means, it can be used over and over again. Waste paper is really a great secondary forest, and its proper use is a great saving to our timber and other natural resources. So before we discuss waste paper itself, let us look for a moment at our forests from which it originally came.

Today there are 461 million acres of commercial forest land in the United States of which 345 million acres are privately owned. This is commercial forest and does not include the innumerable small woodlands on farms which, by a United States Courts decision on April 19 of this year, 1951, was recognized as non-commercial and a part of the farmer's potential crop. In considering commercial forests, let us remember that the total area of the six New England states is approximately 42,649,000 acres and realize that the commercial forests are more than ten times this area, or approximately 22 times the State of Maine. This comparison gives some conception of the size of the industries that deal with the products of these forests. These products are three, namely: lumber; a comparatively small amount of firewood; and pulp. Of these, let us consider pulp.

Last year some 271 mills converted wood from these forests into pulp and 464 other mills converted this pulp into various kinds and qualities of paper, including newsprint. Even with all the newsprint to serve the daily newspapers of the United States, slightly more than two thirds of the newsprint has to be imported from Canada. Moreover, both sulfate and sulfite pulps are imported in large amounts not only from Canada but from Sweden, Norway, Finland, and some smaller amounts from other countries. This much of the pulp situation has been pointed out as a background for our subject which is waste paper.

There are approximately 231 mills operated by 161 companies that are known as board, or paper board, mills. In 1947 these paper board mills produced approximately 10,408,000 tons. In 1950 they produced approximately 12,500,000 tons. This paperboard then becomes the raw material for the paperboard products manufacturer or convertor, as we call them.

We are living in a packaging age, and paperboard's largest use is in boxes, cartons and other packaging. These boxes and cartons are necessary to our every day life, today, more than we think. In fact, they are so necessary that if the paper board mills were shut down, for lack of materials, waste paper, or for any other reason, it would mean the closing of our large department stores, shoe stores, grocery stores, and other business within a few months. Thus, we see that today paper board is a necessity.

In 1950 these paper board mills consumed approximately 7,900,000 tons of waste paper. In 1951 we collected waste paper at the rate of 9,000,000 tons per year and it is being consumed at that rate. This is equal to about 7,500,000 tons of pulp. Since it takes about 1.5 cords of wood, on the average, to make one ton of pulp this

means a saving to our forests of 11,750,000 cords or approximately 2,250,000 acres of forests, figuring an average of five cords per acre.

How does this waste paper of many sorts and quality find its way into the proper grades, properly sorted, processed and baled? How does it find its way into the beaters and hydrapulpers in the mill? Mr. Graham will tell you about that but before he does, let us consider some statistics concerning United States Reclamation of Waste Paper given in Table 1.

You will notice in these statistics that we have gone from a low point of 33 per cent of waste paper reclaimed up to 60 per cent waste paper reclaimed in 1945. That is due first to the demand for waste paper which naturally brings a higher price. We do not build new machines in order to get increased production of waste paper; the only way that we are able to get increased production of waste paper is through price. When the price on waste paper increases it usually takes from four to six weeks before the increased production becomes noticeable.

TABLE I
UNITED STATES RECLAMATION OF WASTE PAPER*

	Total United States Paper and Paperboard Consumption	Per Cent Reclaimable	Tons Reclaimable	Tons Reclaimed	Per Cent Reclaimed
1939	15.948,557	78	12,500,000	4,250,000	34
1940	16,757,305	77	12,900,000	4,250,000	36
1941	20,421,466	75	15,300,000	5,800,000	38
1942	19,780,441	73	14,400,000	5,900,000	41
1943	19,436,672	67	13,000,000	6,100,000	47
1944	19,445,164	62	12,000,000	6,870,000	57
1945	19,665,478	58	11,400,000	6,850,000	60
1946	22,509,788	65	14,650,000	7,470,000	51
1947	24,760,823	75	18,500,000	7,770,000	42
1948	26,106,175	80	20,900,000	7,530,000	36
1949	24,680,867	80	19,800,000	6,467,000	33
1950	25,500,000	80	20,125,000	7,500,000	37

* Preliminary Estimates.
* Percentage reclaimed out of tonnage available within the United States for Salvage.
Source: 1. American Pulp and Paper Assn. 2. National Paperboard Assn. 3. U. S. Department of Commerce, April, 1945 Report "Waste Paper—A Critical War Material."

Introduction to Collection and Usage of Wastepaper

The waste paper industry in the United States represents a volume of business of, probably, $500 million per year. I think it is a fair statement to make that the waste paper business employs 450,000 to 500,000 people. If a business or an industry has that volume and employs that number of people, it certainly has its place in the economic life of the country. I am sure you are impressed with the statistics that Mr. Benedetto gave you as to the importance of the industry over the last twenty years. The business has taken on a dignity which it never had before and people recognize it as a very essential contribution to our present day economy. I want to tell you how we collect this waste paper, how we process it, and how we prepare it for use by the paper mills.

There are really two sources from which waste paper is gathered or accumulated. The first is the household. You gentlemen are familiar with the amount of paper that comes into your own home and what disposition is made of it. The second is what we call industrial collection, or accumulation. The industrial collection includes that paper which is discarded by department stores, printers, book binders, office buildings, hotels, chain stores, paper converters, terminals, envelope manufacturers and any other industrial source.

To give you some idea of what it means in volume, for instance, you are all familiar with the department stores, such as the Jordan Marsh Company in the city of Boston. Jordan Marsh will accumulate approximately ten tons of scrap paper a day. A company like ours will put a trailer truck into their plant every day to remove that paper. A department store like Macy's in New York City, catering to a larger number of customers than Jordan Marsh, and doing a larger volume of business, would probably accumulate twenty-five tons of waste paper per day. I can give you other illustrations. For instance, in the course of a year the New York City obsolete telephone directories are all collected and sold for scrap or waste paper and amount to a volume of about ten thousand tons per year. You could almost say that there are close to a thousand tons of obsolete telephone directories collected in the city of New York every month. That, of course, can make a lot of paper board. Then, when you consider the telephone directories in every other city, town, and hamlet in the country, you will have some conception of how many tons of scrap paper, in the form of those telephone directories, the Bell System would sell in the course of the year. Consider, also, the Sears Roebuck catalog. I am not qualified to tell you exactly how many of these are printed for distribution but there are millions. Just think of what that means if these were reclaimed and came back into the market as waste paper. It involves a tremendous tonnage. They are printed mostly in Chicago, and naturally, after they are printed and bound, they are trimmed. The trim from that catalog alone amounts to thousands and thousands of tons per year.

Collection Methods

Collection methods are varied. For instance, in the case of households, the paper is normally collected and brought into the market by what you gentlemen would probably call a "junk dealer." That is a fellow who, in the old days, went around with a horse and wagon ringing a bell. Nowadays he usually has a small truck. In the industry we do not refer to him as a "junk dealer," we call him a "junk collector." A "junk dealer" is a man who has anywhere from five to twenty-five of these small collectors bringing in the results of their collections to him. The junk collector collects the rags, metals, paper, etc., from households and brings it all in to the junk dealer. The junk dealer buying from these collectors, will segregate the paper, iron, and rags, into different classifications. Then the junk dealer will sell to a company like ours, on a wholesale basis, the result of his collection or packings. For instance, if a junk dealer had twenty collectors and each one brought in a half a ton per day, that dealer would have a trailer load of paper to sell every day and he would be a good source. There are thousands and thousands of such dealers throughout the country.

The Salvation Army is a great factor in the collection of household paper. Companies like ours cannot economically collect waste paper from households. If we were to go to a house and pick up 300 pounds of paper, let us say, in a normal market, which has a value of three dollars at the mill, it would cost us more than that to collect the paper. Companies like ours employ union men and we do not have small trucks capable of going to houses to pick up a few pounds of paper. Therefore, that type of paper comes into the market either through the junk collector, the Salvation Army, The Goodwill Industry, or, when paper is high in value as has been the case in the last seven or eight months, many of the young men of the family will put the paper in the back of the family car and bring it into the market. Just as an example, we have had people

recently bring in scrap paper in the back seat of Cadillac cars getting seven, eight, or nine dollars for the amount of newspaper and magazines that they have been able to pack into the back seat. If the market were low they would not bother to do this. When a fellow can pick up seven or eight dollars in a half hour, or an hour, it is pretty good business. He might like to be doing it all the time.

In the case of industrial paper, such as is collected by wholesalers like Mr. Benedetto and myself, we have big trucks which we send to these places to pick up the paper. The paper comes to us sometimes in bundles, sometimes in burlap bags, sometimes in canvas bags, and sometimes in bales. Some of the paper goes directly to the paper mill from its point of origin. It has been our function over the years to educate people, as far as possible, to pack the paper so that it is suitable for paper mill consumption. If it is not practical, then we bring the paper into our warehouses for segregation and repacking.

Processing Waste Paper

There are many methods by which packers segregate waste paper. Some packers elect to dump it on a conveyor belt, having the sorters, on each side of the conveyor belt, pick out the various kinds. I might point out at this time that there are more than twice as many grades of waste paper than there are varieties of Heinz pickles. If you were to try to outline all of the grades of waste paper, you would easily have over a hundred. Most people do not attempt to sort the paper as completely as that. For instance, to illustrate what I mean by classification: A newspaper has waste from the wrap that comes around the roll, which you have seen coming from the newsprint mills into the newspaper plants. They have the *blank news* which is that last part remaining on the roll, or other unprinted paper. Then they have the *overissue newspapers.* In other words, the publishers usually print more than they sell and consequently, they have *overissue newspapers* for disposal. Then they have all of the miscellaneous waste that accumulates around the press room. There are four classifications of paper from a newspaper plant. From a department store you would get, say ten classifications. From an office building there is what the man at his desk throws into the waste basket and that includes: magazines, envelopes, ledger papers, letters, advertising matter that comes in, and his other miscellaneous scrap paper. From there you would very easily get six or seven different classifications of waste paper. The character of paper which a producer has to sell depends on the type of business that he is in. A low grade of waste paper is called *mixed paper.* Mixed paper that is generated from the department stores is entirely different from the mixed paper that is generated from an office building. It is entirely different from waste paper that is generated from a newspaper, or from a printer. In other words, you have all of these different classifications of paper, depending on the source and the character of business from which it originated.

How many segregations a fellow will make in sorting waste paper depends largely on the economics existing at the time. To illustrate that simply for you: if you had a bale of paper come in and, let us say, to make it simple, you had newspapers and mixed papers in the bale. If the mixed paper price was $15 per ton, and the newspaper price was $18 per ton, that would mean that you would get $3 gross for segregating one ton of newspaper out of the mixed paper. You cannot do that function for $3 and make any money. Therefore, you do not take it out, you leave it in there. The segregation of waste paper is strictly a matter of economics, because the board mill using that mixed paper can use it just as well with the newspaper in as they can if the dealer takes it out. When the mill wants you to take something out of a certain accumulation, they make the economics such that it will pay you to do it, and that is why the function is performed for them.

You might wonder whom we have segregating this paper. Some of the paper is segregated by men, but it is mostly done by women, the same type of women who work in the cotton mills, woolen mills, or any other factory work. The wages which you must pay them are of course the same as they would receive in any other industry, otherwise you would not be able to hire them. When the sorters segregate this paper into the various classifications (they are sorting it, for instance, off the belt, or off the bale without putting it on a belt) they put each kind into a basket, or a box, which one person can conveniently handle. Then there are bins located in the factory which, for economic reasons, are usually built to order, of a size that would contain 1500 or 1600 pounds, and these are set up on wheels. The small baskets or boxes are filled with the special kinds of papers or grades, and those baskets or boxes are dumped into the bins. When the equivalent of a bale is accumulated, that grade is baled by itself. These separate bales are accumulated until you have sufficient quantity to sell to a mill. In other words, if you went to a mill to sell one to five bales of paper, they would not look at you. They would not be interested. You must have sufficient quantity of one variety in order for it to be of any interest to them.

Each grade goes back into what it was, approximately, with the exception of newspapers. The daily newspaper can be made back into a newspaper again, but that has never been either practical or economical. Consequently, all of the newspaper generated in the waste paper market is used by the boxboard mills for making boxboard, usually folding boxes. For instance, if you go into the drugstore today and look around you will see that almost everything they sell is in a box, usually a folding carton. What we call a folding box is that box which is collapsible. Commodities such as cigarettes, toothbrushes, bottles of medicine and such, come in a collapsible box and the base for that item is your old newspaper.

The final step is the baling of the waste paper. A normal bale of waste paper that is made today in the industry, by modern, progressive packers, weighs anywhere from 1,000 to 2,000 pounds. Presses that are used to make a bale that is 72 inches high, 30 inches wide, and, of course, that bale is made in a horizontal position. The weight of the bale depends on how much material you put into the chamber of the baling press. I might illustrate that naturally weigh a lot more than a bale of tissue paper. In other words, the weight of the bale is influenced a good deal by the character of the paper which you are baling.

Conclusion

It is hoped that these presentations have clarified the nature of the waste paper industry and the relationship of it to the pulp and paper industry. It would be helpful to you if the operations of collection and processing of waste papers could be observed.

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Facts Concerning the Waste Paper Industry and Its Relationship to Pulp in the Paper and Paperboard Industries

Paul White[1]

Has been associated with the paper industry for the past 30 years, is President of the Great Eastern Packing & Paper Stock Corp. and also President of General Paper Goods Mfg. Co.

Introduction

The waste paper industry, about which I am going to speak, has grown considerably in the last ten years.

According to the United States Department of Commerce, waste paper consumption in the United States did not exceed four million tons per year prior to World War II. During the war, the demands for waste paper were considerably increased and in 1945 the consumption was approximately seven million tons. In the year 1951, practically nine million tons of this raw material were used. Of this nine million tons, 78 percent was consumed by the boxboard group, 12 percent by the roofing group, and 10 percent by the white paper and tissue group.

Board mills during the year 1951 manufactured more than 13 million tons of paper board and consumed approximately 8,100,000 tons of waste paper in their production. Paper mills produced approximately the same tonnage, namely, 13 million tons, and used approximately 900,000 tons of waste paper.

The figures I have just stated should prove very interesting in comparison to the present pulp production in the United States and also to some statistics concerning our woodlands.

The pulp capacity in the United States was 15,735,000 tons in 1950. In the past year it has been increased slightly and the goal is 19 million tons by 1956. In order to produce a ton of pulp, it requires approximately two cords of wood. The annual growth in the South is 73 million cords and in other areas of the United States it is 69,500,000 cords, making a total of 142,500,000 cords. The number of acres of commercial woodland in the South is approximately 183 million. In other parts of the country there are approximately 276,500,000 acres. The rate of growth in the South per annum is .42 percent, most of which is in pine. In other parts of the country the rate of growth per annum is .25 percent.

Cords of all woods, hard and soft, required for pulp are 38,096,000 cords. For all other uses such as lumber, piling, and manufacturing, it is 120 million cords, making a total of 158,096,000 cords. That use exceeds growth by 15,490,000 cords, or 11 percent. From this it is easy to see how industry is drawing heavily on capital virgin fibres. Analyzing what I have just said, it can readily be understood that if it were not for waste paper, it would be impossible to manufacture the present quantity of paper and paperboard.

It may be argued that standing timber and growth per year insure a supply for over a century. However, the continued drawing on our capital of timber will, regardless of the long-time supply now standing, lead to higher and higher prices for timber land and timber itself. In fact, prices of wood have advanced in the past ten years by 900 percent in the South. Moreover, with a rapidly growing population and ever-increasing new uses for pulp, paper, and paperboard, consumption will not be static but will increase per capita of population. Finally, on this point, reforestation takes time, as long as 20 years, to develop any kind of a growing crop of pine and twice that time, or 40 years, for growth in the more northern states such as Maine. I believe the intelligent answer to this problem is a more extensive use of waste paper in the manufacture of board and paper. Waste paper is a secondary forest. The original fiber in the tree is nature's example of eternal life that can be destroyed only by fire or acid.

From the figures previously quoted, the waste paper industry supplied nine million tons in the year 1951, and it is easy to comprehend what a great forest growth was saved for our country. In fact, if the total land area of the State of Maine (19,865,600 acres) were all woodland, the use of waste paper in the United States last year saved the growth of more than double that area.

The Sources of Waste Paper

There are two main sources from which waste paper is gathered, household and industry.

Household. I will now endeavor to explain how household waste is collected and disposed of. The largest percentage is gathered by junk collectors who go from house to house and, in the larger cities, to apartment buildings, to buy paper, rags, and metals.

[1] Great Eastern Packing and Paper Stock Corp. New York, N. Y.

The junk collector sells his day's accumulation to what is known as the junk shop, where the material is segregated into several classifications. These shops buy from a great many collectors. In the big cities, some junk shops handle many truckloads or carloads of paper a day. The junk shop disposes of its material to a wholesale paper, rag, or metal dealer who, in turn, services mills with large tonnages of the grades they desire.

Other large collectors of household paper are organizations operating on a national basis such as the Salvation Army, Goodwill Industries, and the Volunteers of America. Their institutions throughout the country grade and bale the paper suitable for mill consumption. They usually dispose of their tonnage to large paper brokers but in some instances they sell directly to the mills.

At times when prices for waste paper are high, a sizable amount is brought to market by school and church drives. In this type of drive, the paper is usually brought to central points where large dealers take delivery. This paper is then generally baled and sorted in large waste paper packing plants, for it would be most uneconomical for mills to buy it in its original form.

Industrial. Industrial paper is obtained from all sorts of industrial factories such as printing plants, book binders, department stores, office buildings, hotels, envelope manufacturers, and all types of plants engaged in paper converting.

This type paper is collected by waste paper packers who are usually wholesale dealers handling large tonnages. A substantial portion of industrial paper does not have to be sorted or baled by the dealer for it is graded and packed correctly in the industrial plant. Some of the large industrial plants produce hundreds of tons of waste paper per month.

Should a factory not have sufficient quantities of waste paper to enable them to sort or bale economically, they dispose of it in burlap bags, crates, cartons, and, in many instances, in small bales of unsorted papers.

The waste paper packer sorts and grades this type collection. This paper is all sorted by hand for there is no machinery constructed capable of doing this type work, and the packer will only grade the number of grades which is economical to do, and the balance is disposed of as mixed paper.

The handling of waste paper economically is very important. The mills desire a tightly-compressed bale of 60 or 72 inches in length which weighs anywhere from 1100 to 1800 pounds, depending upon the type of waste paper it contains. All modern waste paper packing plants have the desired equipment for the baling of their paper.

As to manpower, the waste paper industry in its various branches employs between 400,000 and 500,000 people, depending on the tonnage being used by the paper mills.

Waste Paper Classification

Now, the first group of grades of waste paper which I will discuss consists of the following: *folded news, mixed papers,* and *old corrugated containers.* These three grades comprise approximately 80 to 85 percent of the total tonnage of waste paper collected. Of these three grades, *news* is the predominant tonnage, and I believe it is safe to say that 35 percent of the above 80 percent consists of old newspapers, old telephone books, and catalogs, such as those of the Sears, Roebuck and Montgomery Ward companies.

Approximately 30 percent is mixed papers and 25 percent old corrugated containers. The principal users of these three grades are the boxboard mills, and the next largest user would be the roofing paper mills who use principally *folded news* and *mixed papers.* There is also a small tonnage of *news* used in the manufacture of molded products.

The second grouping consists of possibly more than 100 different grades. The principal ones traded in by the industry are known by the following names: white envelope cuttings, hard white shavings, soft white shavings, fly leaf shavings (both groundwood and free of groundwood papers), kraft envelope cuttings, kraft bag waste, 100 percent kraft corrugated cuttings, number 1 old kraft paper, white news blank, manila envelope cuttings, manila tabulating cards, colored tabulating cards, white ledger, mixed ledger, books and magazines, overissue news, mill wrappers, and boxboard cuttings.

The top grade is classified as *hard white envelope cuttings.* These cuttings are obtained from envelope manufacturers in the die-cutting of their paper. This grade may not contain any printed or groundwood content paper. It is principally used by board mills for top liners in the manufacturing of white patent coated board. It is also used as a direct substitute for bleached pulp by tissue mills and mills manufacturing white papers.

Soft White Shavings are generally obtained from magazine publishers and book binders in the trimming of their publications, and this grade is broken down into the following principal classifications: One-cut soft white shavings, No. 1 soft white shavings, and coated shavings.

The top grades are free of groundwood. Inferior grades will contain a percentage of groundwood papers. These grades are used mostly by board mills for liners and by mills manufacturing tissue papers.

Fly Leaf Shavings, procured mostly from magazine and catalog publishers, is broken down into two groups, namely fly leaf shavings free of groundwood, and fly leaf shavings containing groundwood papers. Their principal use is in board mills for underliners and in tissue mills. In some instances, the better grades are used by the white paper manufacturers who de-ink these shavings and use them as a substitute for pulps.

Kraft Envelope Cuttings are procured in the same manner as hard white envelope cuttings, from envelope manufacturers, and are used as a direct substitute for kraft pulp by boxboard, paper, and tissue mills.

Kraft Bag Waste is obtained from kraft bag manufacturers and is also used as a direct substitute for kraft pulp both by board and paper mills.

100 Percent Kraft Corrugated Cuttings are also procured from corrugated box manufacturers and this grade contains two kraft liners with a corrugated medium which may be chip, straw, and other paper mediums which are used in the manufacturing of corrugated boxes. This grade is principally used by the board group.

No. 1 Old Kraft Papers consist of old kraft wrapping paper. This grade also is primarily used by the board group principally for the strength of the kraft fiber.

White Blank News is obtained mostly from newspaper or magazine publishers. It is the waste taken from the newsprint rolls or novel news rolls to be used mainly by the boxboard and tissue groups as a direct substitute for groundwood.

Manila Envelope Cuttings are obtained from envelope manufacturers similar to the white envelope and kraft envelope cuttings mentioned above. They are used chiefly by board mills as a top liner. However, a small tonnage of this grade is used by paper and tissue mills.

Manila Tabulating Cards are obtained from large industrial firms using tabulating machines. This grade is used by board mills for liner and by paper mills where they are de-inked and bleached for use in the manufacture of paper.

Colored Tabulating Cards are procured from the same sources as Manila tabu-

lating cards and their principal use is by the white paper mills who de-ink and bleach them.

White Ledger consists of sheets of ledger, bond, writing papers, and other hard papers which have a similar fiber content, and is primarily used by the white paper mills and the tissue mills. However, a number of board mills use white ledgers for underliners.

Mixed Ledger consists of white and colored sheets and shavings of ledger, bond, writing papers, and other hard papers which have a similar fiber content, and is principally used by the white paper and the tissue groups who de-ink them and bleach this material for their use.

Books and Magazines are procured mostly from household collections and publishers. The white paper mills de-ink and re-use them in the manufacture of book papers.

Overissue News is procured from newspaper publishers and distributors and is used by board mills where they need a strictly clean and fresh news for the manufacture of their products. However, a sizable tonnage of overissue news is exported to India, Indonesia, the Malay States, Philippine Islands, and China where it is generally used as wrapping paper.

Mill Wrappers are the wrappers from newsprint rolls or other types of rolls. They are used mostly by the board group.

Conclusion

As I said previously, these are the grades most commonly traded in by our industry, but there are many other grades of waste paper known as specialty grades and these grades are packed by dealers for mills requesting special packing. It would be impossible for me to discuss these numerous grades in the short period of time allotted to me.

In this brief talk, I trust I have given you a fairly clear picture of the waste paper industry and its importance to the paperboard and paper industries, and also its contribution in helping to preserve our natural resources.

Beating and Refining

C. K. TEXTOR

Graduate, Chemical Engineering, University of Wisconsin. First employed at the Forest Products Laboratory in Madison for a period of about four years. Was then employed in the industry for a period of about twenty years in various technological, supervisory, and managerial capacities; the longest being with the Northwest Paper Co., Cloquet, Minn., but for briefer periods with the Nekoosa Edwards Paper Co., the Howland Pulp and Paper Corp. and the Riegel Paper Corp. For the past ten years he has been engaged by Bauer Bros. Co. in the development and sales of refining and cleaning apparatus for the pulp and paper industry.

Introduction

This lecture is not going to be a description of any new theory concerning what happens in beating and refining. Nor is it going to involve much detail concerning past and present theories along these lines. It is, rather, a more or less personal opinion story based on practical experience, theoretical thinking, and factual description. I am afraid it will be somewhat random in character but the main theme throughout will be a personal conclusion that there is no adequate scientific theory to explain and control the beating processes, and that what we know about beating and refining is merely the so far unclassified results of experience in commercial operations or in laboratory experiments.

In a consideration of the overall picture of papermaking, in which beating is an important step, it would seem only logical to conclude that the scientific aspects of refining should be rather obscure because, in spite of a tremendous amount of study in recent years, we really know very little about the science of the raw materials of paper. We especially know very little about the principal ingredient which we call fiber, cellulose or pulp. It is only reasonable to conclude that the comprehensive science of refining will follow immediately after we have grasped the basic science of the raw material.

For the most part, the considerations of this paper will be confined to comments concerning wood which is today the preponderent raw material in the manufacture of paper. Let us briefly review just what we know about this substance.

Wood Constituents

Just what do we actually know about this raw material, wood Our literature on this subject seems to be very final and definite, as do most of our conversations. We say that wood contains 60 to 65 percent cellulose, 20 to 25 percent lignin, and the remainder is comprised of pentoses, gums, waxes, ash, etc. This all sounds pretty definite.

It is not difficult to find definitions for the first of the ingredients of wood, that is cellulose. These definitions are generally accompanied by a fairly definite chemical formula, and it is found that for a good many purposes this formula will suffice. Generally, the definition is accompanied by some sort of a statement that cotton is the purest form of cellulose. But if we examine the definition further, and note how firmly the definition is predicated on the properties of cotton, we inevitably come to the conclusion that instead of cotton being merely the pure form of cellulose as found in nature, the fact remains that, to all intents and purposes, cellulose is cotton.

In the chemistry of wood, cellulose is generally taken as the white fibrous residues remaining after wood has been treated emperically in a succession of physical and chemical procedures, largely patterned after the work of Cross and Bevan, the pioneering English cellulose chemists. When this Cross and Bevan cellulose determination procedure is applied to wood, and

all details are religiously observed, checking results are obtainable, and the residual white fibrous substance does resemble cotton in most respects. Incidentally, this Cross and Bevan determination of cellulose in wood has been rather basic in the thinking and activities in pulping research of the Forest Products Laboratory of Madison, Wisconsin, practically since its inception about 1910. This thinking was predicated on the rather obvious possibility that by proper treatment of the wood a yield of 60 percent or more of white papermaking materials was obtainable, rather than the 40 to 45 percent yields which were customarily obtained in commercial practice in the chemical pulping of wood chips. This goal of obtaining high yields of pulp from wood has led to the development of the neutral sulfite semichemical process about which the Forest Products Laboratory has written so much in the past 25 years, and to the more scientific approach of Dr. George Ritter of that institution, which has developed the idea of holocellulose and its possibilities.

In the early stages of the investigations conducted by the Forest Products Laboratory, a great deal of the data which is available today was then lacking and the goal initially was merely the potential of the 60 percent Cross and Bevan cellulose. Later on it was recognized that perfectly good and useable chemical pulps would show only 90 percent Cross and Bevan cellulose and so the sights could be raised so that substantially in excess of the 60 percent Cross and Bevan cellulose could be expected in the form of good, useable "papermaking materials."

As in the case of cellulose, lignin likewise is spoken of very definitely although it likewise is merely a residue after a certain series of chemical reactions which are basically empirical and which must be followed scrupulously in order to get checking results. But really, this results in only a sort of qualitative knowledge of lignin. A few years ago the Institute of Paper Chemistry in Appleton, Wisconsin, conducted a symposium on the constitution of lignin in which wood chemists from all over the world took part. The findings, theorizings, and discussions of this meeting, in condensed form, were published as a pamphlet which ran into over one hundred pages. It would be well to remember that this pamphlet was not a compendium of lignin technology, it was merely conjecture concerning the composition of the substance.

In a similar manner, we speak very definitely about alpha cellulose. And indeed, alpha cellulose is a substance which is on the market under that name. It again is a residue remaining after a series of chemical treatments, in which the impure cellulose is presumably freed from the less chemically resistant forms of cellulose and other extraneous matter. But, if you subject this pure alpha cellulose to another alpha cellulose determination, you will find that on the second determination, the proportion of alpha cellulose is not a great deal higher than it was on the original impure pulp. In other words, it is probable that alpha cellulose, rather than being a definite substance, is really representative of the condition of the cellulose, rather than being in itself a stable form of cellulose.

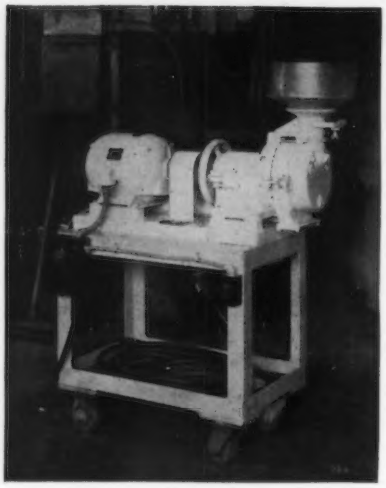

Figure 1—Laboratory Size Single Disk Mill; 8 inches in diam.; 7½ H.P.

This brief survey of the status of wood chemistry may sound like an indictment of the procedures involved. But this is not the intention by any means. The statements were presented merely to show the limitations of our knowledge concerning our raw material, and to indicate the difficulties in formulating any clear cut science involving the beating and refining of this material. If it serves to indicate to you that our general language concerning the chemistry of wood is over simplified, and full of pitfalls unless this situation is kept in mind, these comments will serve a useful purpose. The facts, as they seem to me, are that even these beginnings of the science of wood physics and chemistry offer wide scope of application.

Beating

In all probability, some form of mechanical treatment, such as pounding, stamping, crushing or grinding, was used in the separation of fibers and their preparation for sheet forming from the earliest days of papermaking. But what we now think of as beating and refining necessarily began with the mechanical age, about one hundred fifty years ago. At that time, crude machinery, power driven, began to be substituted for the strictly manual operation involved in papermaking. As paper forming machines, such as the fourdrinier, developed in speed and efficiency, it became more and more important to develop mechanical means for preparing fiber for these machines. In the intervening period, literally thousands of different ideas of machines for the mechanical preparation of fibers were proposed and tried. Of all of these, only the beater and the jordan have been completely proven by the test of time. Most of the others have completely fallen into dis-use. Some others, such as the kollergang and the rodmill, hang on precariously, whereas disk mills, which, in various forms, have been repeatedly tried in the past, seem to have a promise of becoming a third class of instruments for stock preparation.

What we know as the beater was first brought out about 150 years ago under the name of the Hollander engine. In the meantime, the beating engine as employed in the paper mills has undergone changes in appearance, capacity, and motive power, but the general principles of the old time Hollander continue to be the dominant features of the modern beater.

About one hundred years ago Mr. Jordan brought out his refining engine which has had such universal acceptance that the capital "J" of Jordan has been eliminated and his machine is employed under the simple name of jordan. Like the beater, this has undergone some change in appearance and capacity but the principles of it remain unchanged. The biggest change involved in the use of the jordan is that it is better adapted than the beater to high production procedures. In the past twenty-five years it has made enormous strides in eliminating beaters.

Both of these refining devices can be considered traditional. The papermaker is supposed to know just what he can do with these devices, and the manufacturer is merely supposed to put out a good, worthy, efficient machine.

Practice of Beating

No doubt all of you are familiar with the old adage that "paper is made in the beater." Initially, this statement meant just what it said and continued to mean that almost exclusively until about fifty years ago. During all those first years, the beater was the main instrument of stock preparation while the jordan and other engines that were used were somewhat dispensible additions and generally went under the name of refiners, regardless of what their action was. Those were the days in which old rags constituted the principal source of fiber for paper; but with the advent of wood fibers for papermaking and their in-

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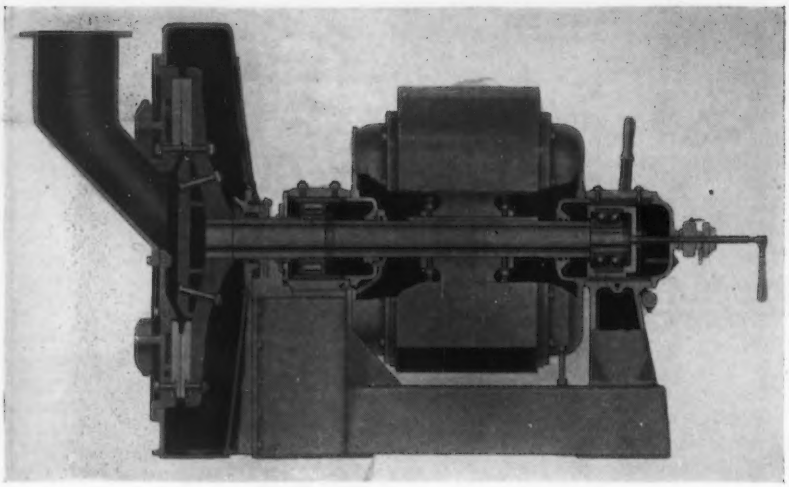

Figure 2—Non precise Single Disk Mill; 36 inches in diam.; 200 H.P.

creasing use, jordans became more popular and the later day beater engineers would extend the adage to take in both the beaters and the jordans.

These old time beater engineers could do marvelous things with fibers. They had no instruments for measuring but proceeded merely by looks, feel and sometimes by the chewing qualities. The old adage of making paper in the beater can be readily translated into a statement that beating and refining was an art. It is worth some consideration to look at the facts as we have them today and see just how far away from the art we have progressed.

In the strictest interpretation of this old saying, a modern newsprint mill, for example, which has no beaters, would obviously then not be making paper. If we could revive some of these old time beater engineers, no doubt they would confirm this opinion. What we are using as newsprint paper today was completely unknown fifty years ago and some of the real old timers might say it is a sheet of something but certainly not newsprint paper as they knew it because, up to about 1890, some newsprint paper was made entirely from rags and all newsprint paper had a considerable rag content.

During the early days of the Forest Products Laboratory at Madison, Wisconsin, the staff included an expert paper maker, an Englishman by the name of Joe Laing. He was rated as an expert and he really was one. He was born in England and started to work in paper mills when he was twelve or fourteen years old and had done nothing else during the rest of his his life. He was about sixty at the time.

He had come through all of the then current stages of apprentice, journeyman, and master. He had also followed the then current procedure of getting experience by working in one mill after the other. His journeyman experience had taken him around the world, including a considerable time in Japan. At that time, the Forest Products Laboratory depended largely upon actual runs on a miniature paper machine because our sheet making equipment had not been properly developed at the time. It became my particular job to translate the results which Joe Laing obtained on the paper machine into some kind of order which would permit duplication. Joe was willing to teach me. He explained in detail just how he conducted his refining operation. During the first hour or so, the operation of the beater was critical inasmuch as at that time the fiber could be completely ruined. After that time he would lower the roll gradually to the stages of light brush, and heavy brush, and finally come to the point where the fiber could no longer be ruined and he could put the roll down hard. Then, to quote him verbatim, "When the fiber gets just right, you drop it."

Joe Laing was a real beater engineer. He knew the answers by feel, touch and experience and this knowledge could not be quickly transmitted.

In the past fifty years, the wonderful progress of papermaking in general has been accompanied by like progress in beating and refining. The technology, if not the science of refining, has largely developed since that time. The development has been in the direction of low cost, high production papers rather than the extremely high quality papers which, after all, were the grades which were referred to when "paper was made in the beater."

Furthermore, the development of cooking and grinding processes has kept pace with the other developments and, more and more in recent days, the quality of paper is being determined in the digesters, and bleachers, and grinders, and less and less by refining. As previously indicated, the refining is being accomplished more and more by such production equipment as jordans and disk mills and less and less in the beaters.

In the following comments, for the most part we will refer to this mechanical action as refining, rather than indulge in quibbles over the type of equipment in which the refining takes place. It has been pretty clearly demonstrated that the differences in action between the beater and the jordan are not as profound as they used to be considered, the differences being largely involved in items of consistance, pressures, and rate of refining.

For the most part, in the course of the last twenty-five years, we have developed a great many tests and metering devices for the determination of freeness, drainage rate, viscosity, and a host of other characteristics. Without question, these are all useful guides for the production of paper in general and for particular grades of paper. But is there anybody that can take an unknown fiber and, from the combination of any or all of the tests which we employ. describe a refining treatment to give the qualities desired in a sheet of paper? Unfortunately, we still have no scientific beating. We must rely to a considerable extent on trial and error and depend on experience in the mill and laboratory experiment. The biggest difference is that today this experience is recorded and tabulated. We no longer depend on the carefully guarded secrets of the skilled artist known as the beater engineer.

To the jargon of the old beaterman, which included such phrases as "wetting," "hydrating," "brushing," "drawing out," and "cutting," we have added new terms of "freeness," "slowness," "drainage rate," "gelatinizing," "filbrilating," and "inch cuts per minute."

All of these phrases are set around with "booby traps." At best, they have a uniform, definite meaning only to a small group. Take for instance the term "hydration." Almost everybody has his own conception of just what is covered by this term and unfortunately, the several ideas of what constitutes a hydrated fiber are subject to enormous variations. This situation results in great confusion. Frequently, merely because of the use of the same words but with a different conception of their meaning, people seem to be entirely in agreement when they actually are "poles apart." Conversely, sometimes people are in thorough agreement while their statements seem to be contradictory.

Avoiding all these pet phrases, what we do know is that continued mechanical pounding or treatment of fiber in the presence of water develops in a pulp different and somewhat desirable properties of paper made from it. The pulp becomes stronger, retains water more persistently, by some phenomenon which is probably a combination of physical and chemical change, it drains more slowly, and there are other changes for which we currently have no means of measurement. For the most part these refining changes cannot be reversed. In other words, the fibers are no longer exactly what they were to begin with. We know these things

and many others about fiber although for the most part in a descriptive or technological way.

Through the years, there have been repeated and persistent attempts to formulate our knowledge of fibers into a working formula. None of these attempts or theories has lived very long simply because they were adequate, at best, for only a limited scope in the field of beating and refining. No attempt will be made to describe these many theories, or even to enumerate them. But there is one which made a tremendous impression upon me when I first read it and which might serve in a way to illustrate some of the plausible theories that have since gone by the board.

About twenty years ago a European paper technologist published a treatise on refining in which he developed the basic idea of "inch cuts per minute." This was published in book form and, because I could not agree with the findings, I gave it a very thorough study. It contained a wonderful mathematical presentation of his thinking, and nowhere in the body of the book could I find any fault with the logic. Nonetheless, the conclusions did not seem to support experience. It was not until I read the introduction that I discovered, as I believe, just where the error lay. The entire structure of the treatise was predicated on some assumptions included in one paragraph in the introduction. There the author assumed that all properties of paper were determined by a combination of fiber length and "hydration." Fiber length was to be determined by actual measurement by means of a microscope and "hydration" was determined by the use of a freeness tester. These ideas generated a lot of discussion twenty or thirty years ago but I believe that today they are almost completely forgotten.

The latest theory put forward to explain, or partially explain, why paper fibers hang together has been lately expounded by Dr. Marks of the Brooklyn Polytechnic Institute. Dr. Marks develops his idea through the medium of modern chemistry and physics. While, it seems to me, Dr. Marks fails to explain the entire phenomena on beating and refining, he does feel that there are four ways in which fiber properties are developed by the mechanical treatment.

Current Practice

Today, almost any pulp or paper mill of any consequence maintains a laboratory which conducts tests and evaluations for the control of the properties of their product. This applies to the refining operations as well as the other procedures in manufacture. There we have such practices as pulp strength evaluation by means of minature refiners, freeness, mullen, tear and fold measurements as well as a myriad of other specialized tests pointed toward control of the properties desired for special purposes.

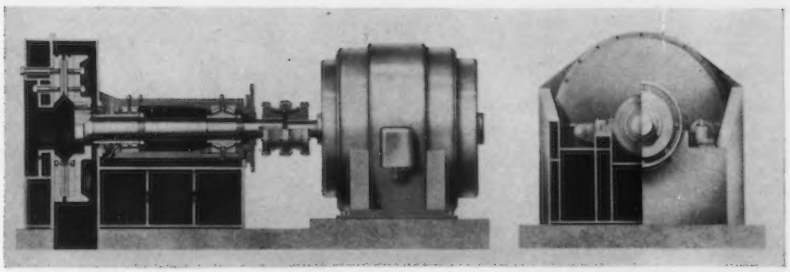

Figure 3—High precision Single Disk Refiner; 44 inches in diam.; 600 H.P.

Only a few of the really vital properties are currently being adequately measured. For example, just what properties does pulp have to possess so that it can be made into paper at the rate of 1500 or 2000 feet per minute. The strength of dry paper is not an adequate guide. Frequently, very strong dry paper can be made out of a fiber which is very weak at the couch roll. This applies particularly to semichemical pulp made from hard woods . It would seem that a strength test on the wet sheet would be a controlling factor in this consideration but, to the best of my knowledge, no satisfactory method of such a test has yet been developed.

As was the case described in connection with the chemical properties of fiber, these physical tests must be used with discretion. To illustrate, a freeness test is an excellent measure of the runability of fiber on the wet end of the paper machine. This works beautifully, especially in the manufacture of newsprint paper, in which the runability of the furnish is largely determined by controlling the freeness from the grinders. But this freeness testing is not an unmixed blessing. It has been noted that as refining progresses the freeness drops; the mullen test increases to a maximum and then drops, for the most part; the tear test begins dropping at once and continues, although at a decelerated rate. So, in many cases, a determination of the freeness is an excellent measure of the mullen strength and the tearing resistance which has been developed in a given fiber. As a result, inasmuch as freeness is much easier to measure, and quicker than a determination of the mullen and tearing of a fiber, it has been substituted for the direct determination on the grounds of expediency. At the same time, the paper maker would generally much prefer a pulp at a higher freeness if at that higher freeness he could obtain the strength properties that he desires. After this system of determining strength properties by means of a freeness test has become a routine, however, there is a tendency to forget that it is an indirect method and sometimes results in the operators considering that low freeness is the end that they desire rather than a necessary evil accompanying it.

Such oversights are apt to result in embarrassment or worse. As an illustration, one of the prominent paper mills of the country was making a study to determine how, by refining procedure, they could develop properties which they desired and, at the same time, maintain a higher freeness. This project was headed by a highly competent technical man, who before and since that time has had a successful carreer. At the moment he ignored the fact that freeness is only an indirect measure of strength, obtained only when one material is treated by a definite train of refining equipment. The result was that in this program of trying out a whole series of different refiners and procedures, with the objective of developing strength qualities without too much loss of freeness, he had set up a measure of effectiveness of the different refiners on the basis of the freeness drop which they caused per horsepower of refining applied.

Another much abused evaluation is the old reliable mullen tester. This is an easy test to make and mullen testers are found literally everywhere. The result is that mullen tests are made and mullen test specifications set up for countless qualities of paper in which the bursting strength has no significance whatever.

While there is a widespread tendency to overestimate the importance of some of the standard tests used in studies of refining, it is fortunately possible likewise to find places where these tests may be applied to advantage better than can ordinarily be hoped for. Some years ago in an attempt to correlate pulp properties, as determined by standard tests in a laboratory beater, with those obtained in the mill from full commercial sized beaters and jordans and a standard fourdrinier paper machine, an example of this unexpected

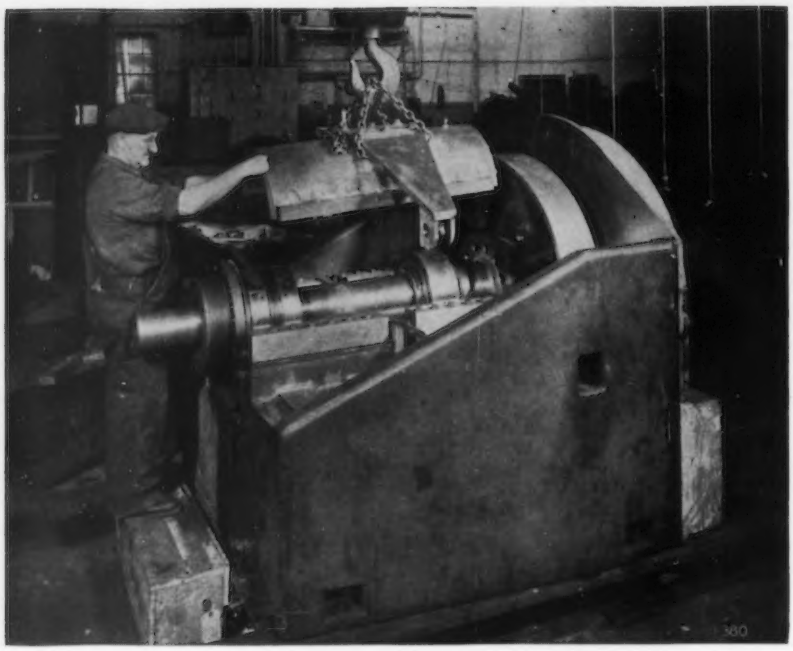

Figure 4—Large Single Disk Mill in process of assembly.

value of laboratory tests was disclosed.

The papermaker thought that such an attempt was complete folly because, to quote, "You can't expect us to duplicate with this big, fast running machine the results you obtained with a little hand mold in the laboratory." The technical staff agreed with him entirely but persisted in trying to obtain a correlation between the laboratory hand sheets and those produced on the commercial paper machine. After a great deal of unsuccessful effort, it was realized that the stock running from the headbox onto the fourdrinier wire was not really the fiber from which the paper was made. Depending upon the grade of paper being manufactured, anywhere from 20 to 40 percent of the material going onto the wire went through the wire and was recirculated through the system. The actual fiber from which the paper was made was the wet broke. The next best place to sample was at the discharge of the last jordan before the machine chest. In this way, the complications due to the addition of white water were largely avoided. When the laboratory procedure was altered to take this factor into consideration, it was discovered that the paper machine itself is really a remarkable machine. The quality of the machine-made paper, when both tear and mullen strength was considered, was substantially equal to that made in a hand mold when the handsheets were made from fiber prepared by the commercial beaters and jordans. The conclusion from this obviously is that the failure of the paper mill to produce qualities as good as those made in the laboratory was not a question of formation and drying, but was primarily one of refining technique.

As previously suggested, many of the ideas and conclusions of 25 or 50 years ago have to be scrapped because of changing conception of paper making and changing techniques of making it, as well as change in quality of the bulk of the tonnage of paper being used today. The old time conception of making paper contained three definite steps, quite separated from each other: From the digesters, to the beaters, to the paper machines. As indicated before, even in this old conventional setup the modern conception has brought about some changes because of closer control of the cooking operations so that less refining, and sometimes no refining, is required. Similarly, in the grinding of wood to mechanical pulp, it is the unusual mill today which employs a refiner to any appreciable extent. Added to this, there is the recent necessity of obtaining higher yields of pulp from the wood which has brought the semi-chemical processes into the picture in force. More lately, the practice of refining hot stock from the digesters has come into being.

Disk Mill Design and Operation

For well over a century, the papermaker relied almost exclusively upon beaters and jordans for his refining requirements and so there has been built up a considerable literature concerning the design and functioning of these engines. This paper will not attempt to go into that literature but will confine its discussion to the newcomer in the refining field, the revolving disk mill.

Although the history of the successful use of disk refiners in the pulp and paper industry is rather brief, a considerable variety of forms and sizes have become available to the industry. For the most exacting refining jobs, disk mills of machine tool precision can be supplied. Less precise and less expensive disk refiners are available for breakdown jobs and cruder refining. In the various designs, one disk may rotate against a stationary disk, or both disks may revolve in opposite directions. The several modifications provide for disks of practically any desired diameter up to 48 inches.

There is a similar spread in the power which the several types of refiners are designed to accept, ranging from fractional horsepower units up to individual machines, of either double disk or single disk modification built to accept 600 brake horsepower. Similarly, a wide range of speed of operation is contemplated in the several designs; various mills are built to operate at as low as 300 revolutions per minute and at as high a rate as 3600 revolutions per minute. A few representative mills of the considerable number available are illustrated in the following photographs and drawings.

Figure 1 illustrates a laboratory size single disk mill which may accept up to 7½ horsepower and operate at any synchronous speed up to 3600 revolutions per minute.

Figure 2 pictures a non-precise 36 inch single disk mill designed for speeds up to 1800 revolutions per minute and for a maximum of 200 horsepower. This is an excellent mill for preliminary breakdown jobs and for crude refining but cannot be recommended for the more exacting requirements.

Figure 3 pictures a highly precise single disk mill with a 44 inch diameter disk which is designed to operate up to speeds of 1200 revolutions per minute and with motors up to 600 horsepower. It has a water cooled frame to avoid thermal distortions and is recommended for the most exacting jobs.

Figure 4 is a photograph of the same machine in the course of assembly and will better illustrate the massiveness of construction.

Figure 5 illustrates an installation of a semi-precise double disk mill, having two 36 inch revolving disks and two

150 horsepower motors. It is provided with a cast iron base and, while it is a completely adequate machine for many purposes, it is not to be recommended where extreme precision is essential.

Figure 6 is a wash drawing of a precise double disk mill with 40 inch diameter disks and equipped with two 300 horsepower motors. It is provided with a water cooled steel base for mechanical and thermal stability and is recommended for uses in which precision is necessary.

Revolving disk mills are simple in conception. In the single disk modification, it is merely a disk hung to an extension of a motor shaft so as to rotate in close proximity to a similar disk which is held stationary. The surface of each disk is grooved according to some desired pattern. Generally, this working surface is designed to be replaceable and is comprised of several segments which may be bolted to the disks themselves. Provision is made so that the clearance between the plates is accurately adjustable. The material to be refined is fed by gravity or by pressure, through an opening in the center of the stationary disk, and after refining the pulp is collected in a case surrounding the disks and is discharged by gravity from the bottom.

The double disk construction is similar except that the stationary disk is eliminated and replaced by another motor with a disk hung on to its extended shaft. The stock to be refined is fed into the central refining zone through the spokes of one of the revolving disks or through a hollow shaft. This imposes some feeding difficulties on the double disk design which is especially limiting when long stringy materials are involved but which is of little consequence when pulp or chips are to be refined.

Whether the machine be of the single or the double design, parallelism of the rotating disks is essential. It is not enough that the refiner as constructed have this parallelism; it is demanded that the design and the construction be such that this parallelism is not distorted due to mechanical or thermal causes while the machine is in operation, either in the machine itself or in its foundation.

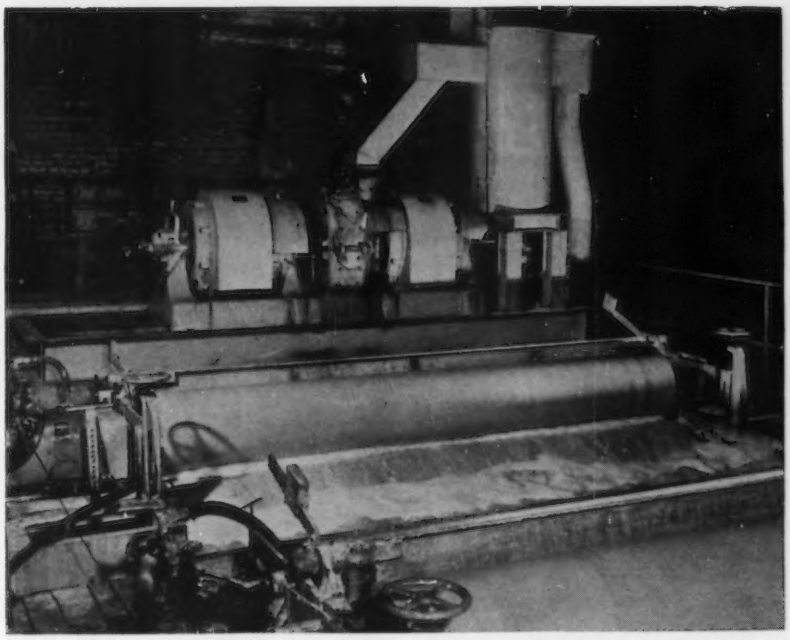

Figure 5—Installation of Semi-preices Double Disk Mill; 36 inches in diam.; 300 H.P.

Just what happens to fibers which are processed, in the presence of water, through a disk mill is just as obscure as the item of what happens to fiber in a beater or jordan. In all types of disk mills there is obviously violent agitation and a distinct tendency to rub and roll the materials between the working surfaces. Cutting of fiber is limited, especially at higher speeds. There is a real difference between the refining action of a single disk mill in comparison with the performance of a double disk refiner. The differences are readily observed and conjectural explanations may be offered. It is easier to feed a double disk mill by gravity as compared with a single disk mill at the same speed, and likewise it is easier to retain the material longer between the disks of the double revolving unit. But beyond these and similar generalizations, we must depend upon operating experience and laboratory experiments with full scale refiners, when it is desirable to choose between the several types of mills, to forecast quality expectations and power requirements and to select optimum speeds, plate design, consistencies, and feed rates.

Miniature disk mills may be used in the same way that miniature beaters and ball mills are traditionally employed in the laboratory evaluation of pulp quality. But, as in the case of the miniature beater, the results of refining with miniature disk mills are of little value until after they are correlated with results obtained from commercial sized units.

Fortunately, disk mills lend themselves well to small scale experiments in refining with full commercial scale disk refiners. There are only a few ounces of stock in the refining zone of a revolving disk refiner at any one time, and, because the case is run empty of fiber, the power of refining drops to the idling load of the motors promptly after the stock supply is cut off. When a refining job is such that the mill can be fed by gravity, it is entirely practicable to obtain thoroughly reliable results with a 15 pound sample of pulp to be processed through a 300 horsepower refiner.

For such laboratory investigations of the performance of commercial sized refiners, all that is necessary is the refiner, a means of supplying it with a

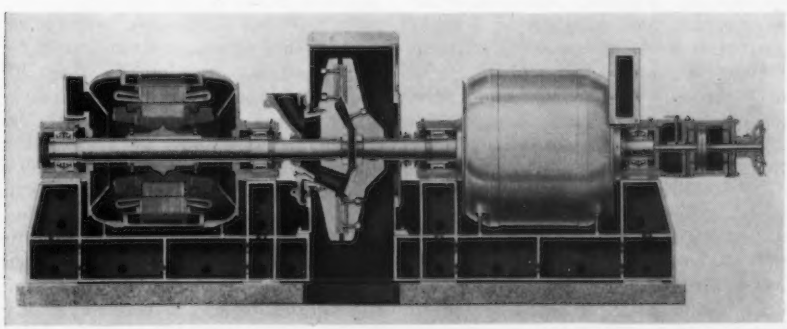

Figure 6—Precision built Double Disk Mill; 40 inches in diam.; 600 H.P.

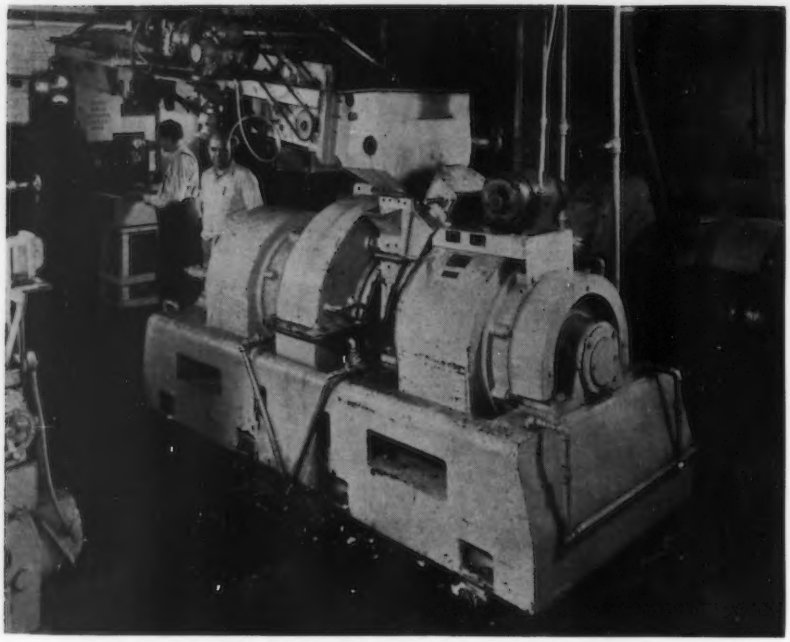

Figure 7—Double Disk Mill and accessories for refining experiments.

regulated quantity of fiber and water, an accurate watt-hour meter, and a means of evaluating the refined pulp. *Figure 7* illustrates the equipment required for such refining researches. The refiner pictured is a commercial unit, powered with two 300 horsepower motors. Above it and discharging into its spout, is a variable speed belt upon which a weighed quantity of pulp or chips is uniformly spread. The belt is arranged to deliver into the disk mill at any rate up to 200 tons of dry fiber per day. The consistence is controlled by providing an overhead water supply tank with calibrated adjustable orifices which are piped to the spout of the refiner. The power requirements are read to the nearest one hundredth of a kilowatt-hour. The quality performance is determined by means of the usual equipment and procedures employed in pulp laboratories comprising freeness testers, sheet formers, a constant humidity room, and the standard devices for measuring bursting strength, tearing resistance, folding resistance, and tensile strength.

As above explained, basic science offers little help in writing specifications for refiners, but the years of experience in mill scale operations and in laboratory experiment with full scale disk mills has outlined a few rule of thumb guides to aid in selecting the best adapted refiner and in predicting its performance. This experience has indicated that the action of the disk mills may be grouped into three categories of (1) fiberizing, (2) dispersing, (3) quality development. Fiberizing may be defined as the reduction or resolution of aggregates into their individual fiber components, whether these aggregates be raw chips, screen rejects, semichemically cooked chips, or old paper. Dispersing is that type of colloid mill action which results in the disintegration and dispersal of friable dirt, soft shives, pitch, and similar materials, so thoroughly that they cannot be seen with the naked eye. The third category, quality development, is that function, formerly the exclusive territory of beaters and jordans, by which the strength and other desirable treatment are not sharply defined genproperties of fiber are developed.

These three functions of disk mill erally. For example, all fiberizing treatments are accompanied by some dispersion and by some quality development but the type of mill and the refining procedure can be chosen to foster particularly any one of these performances. Fiberizing is fostered by high speeds, 900 to 1500 revolutions per minute, and high consistence, 8 to 12 percent. Dispersing is most effective at higher speeds and low consistence, 3 to 4 percent. Quality development is more complicated; when strength development is the main requirement, there is a preference for low speeds, 450 to 900 revolutions per minute, and medium density.

Translated into practical application, the above generalities indicate that when fiberizing or dispersing is the main requirement, it is likely that a high speed double disk mill will best serve the purpose. When strength development is the main requirement, a low speed single disk mill will probably give best satisfaction. Very frequently it is desired to incorporate into one step, two of the above categories, as fiberizing, and quality development. Frequently the tougher job is that of fiberizing, and by the time the aggregates are thoroughly reduced to individual fibers, their strength has been satisfactorily developed for the purpose. In such case, the one treatment will suffice. But in others, especially kraft screenings, a good deal of power is required for strength development after the screenings have been thoroughly fiberized and this may indicate a double disk mill followed by a single revolving disk model, or possibly either of the above running at medium speeds.

Specific Applications

The revolving disk mill has proven itself very flexible because of the considerable number of controllable variables such as speed of rotation consistence of feed, pattern of working surface, temperature of operation, the clearance between rotating plates, and many others. In consequence, we find disk mills in successful operation in wide variety of unrelated applications.

Pulp Mill Screenings

It is in connection with the successful refining of rejects from the screens of pulp mills that the disk mill first entered the industry. These refiners are well established in the groundwood industry, in which the screen rejects are refined, using about 40 horsepower days per ton when the accepted groundwood requires 70 to 75 horsepower days per ton and when the refined rejects are to be included with the accepted mechanical pulp, which is the regular practice. When the refined rejects are to be used in other grades of paper or board, the power requirements are generally substantially less, depending on the specific situation. But one thing is uniform practically throughout and that is that the fiber from the refined rejects is longer, stronger, and freer than the groundwood pulp itself. The refining of sulphite rejects is another established achievement of revolving disk refiners. This is a low power job requiring 5 to 10 horsepower days per ton and in which either the single disk or the double disk mill may be successfully applied. The product from the fine screen rejects is substantially equal to that of the accepted sulphite pulp except for color and is frequently combined with the accepted pulp and used as such. The product obtainable from the knotter rejects is poor in quality both as regards color and strength. Likewise in connection with kraft

screenings there are numerous successful applications. The power requirements are in the neighborhood of 10 horsepower days for fiberizing and equal amount for strength development.

Semichemical Pulp

This is a relatively new and rapidly growing activity, and is practically dependent upon the performance of revolving disk refiners. While there are almost an infinite number of combinations of type of chemical, proportion of chemicals, cooking temperature and cycle, and other variables possible in the production of semichemical pulp, the commonest procedure in service today is the neutral sulphite semichemical system designed to produce yields in the neighborhood of 70 to 75 percent of unbleached fiber. In most cases, the semichemically cooked chips definitely require fiberizing and, if this fiberizing is thorough, generally the strength is adequately developed without subsequent refining For the most part, it has been our experience that the best mill for this service is a double revolving disk unit operating at 900 to 1200 revolutions per minute and requiring 10 to 15 horsepower days per ton in a complete preparation of fiber, beginning with merely softened chips. The procedures designed to obtain still higher yields, in the range of 85 to 90 percent, will necessarily require more fiberizing power, in the neighborhood of 20 horsepower days per ton or even higher. Typical of these very high yield procedures is that of the cold caustic soak described by the Forest Products Laboratory and which is currently in commercial use. In some of these applications, it will doubtless be discovered that a double disk fiberizing is best followed by a single disk strength development although this must be determined by specific research.

High Yield Pulps

This activity is really a part of semichemical pulping. As generally operated at present, the discharge of high yield pulp from a digester contains somewhere between 10 and 30 percent of the chips that are not broken up in blowing. These chips are truly semichemically cooked wood. The rest of the pulp that is broken up during the blow resembles semichemical pulp very closely. There are two approaches to the refining required in connection with high yield pulps. One comprises the removal of the chips for separate refining, the separation being achieved either by a screen ahead of the washing equipment, or the refining may be postponed until after the mass is washed. A second system involves the refining of the entire mass of pulp prior to washing; this second procedure is generally referred to as hot stock refining. In current practice, only the first of these approaches is being employed in connection with high yield sulfite, although both systems are in use in high yield kraft operations. The double disk mill seems to work out best when the uncooked chips are removed from the pulp prior to refining whereas the single revolving disk unit is preferred, for a number of reasons, in the hot stock refining.

Dispersing

This procedure has been most successful, to date, on sulfite pulp, which contains soft shives and friable dirt which, by the colloid mill action of the disk refiners, may be dispersed so that they are no longer visible. When a double revolving disk refiner, set up for dispersing operation, immediately precedes a paper machine, a definite improvement in formation can be noted, and a profound effect is achieved in the dispersal of pitch so that its accumulation on felts and wires is radically reduced. These are low horsepower operations requiring in the range of 2 to 4 horsepower days per ton and are accompanied by a modest development of bursting strength and a negligible change in either tearing strength or freeness.

Stock Preparation

Jordans are the traditional equipment for stock preparation and the resistance to change is most noticeable in this field. But disk refiners are gaining acceptance even in this area and, while a great deal of experimental work is still required to find the equipment and procedures best adapted for the many desired qualities to be developed in stock preparation, it is predicted that the use of disk mills in this activity will definitely be on the increase.

In comparison with jordans and other knife edge refiners, disk mills cut substantially less, and are able to develop strength at higher freeness and higher tearing resistance. When the principal considerations are power and bursting strength, a single disk mill at slow speeds is preferred. For other grades, different treatments are required. Gradually data are being collected although currently there are relatively few commercial uses of disk mills in stock preparation applied to chemical pulp except in the container board field. But there is ever increasing interest in the possibilities of disk mill treatment of pulps especially in connection with sulfite, soda and even groundwood. In these pulps, disk mill treatment has developed desirable properties in pulps which in recent years have not had any refining treatment at all. But the changing economy and the scarcity of wood, especially soft woods, demand higher yields and at least equal or improved quality of product. These factors seem to be in the realm of practicality for revolving disk refiners.

Waste Paper

The breaker beater or one of its modern equivalents is essential as a means of reducing waste paper to a form in which it may be pumped. Some types of paper yield so readily to mechanical action that they are completely fiberized by a short treatment in a breaker beater. Unless this situation is obtained, the action of the breaker beater is best supplemented by a treatment in a revolving disk mill. There are many successful applications of this type but they are diverse in nature and only a couple will be mentioned to illustrate the general application. Usually, these are fiberizing and dispersing operations and so double disk mills at high speeds are preferred. These mills are employed in de-inking plants, either for a preparation of the fiber prior to cooking or in a position following cooking to disperse the ink prior to washing. In container board plants, disk mill treatment has more merit when applied to liner stock where tear, fold, and coverage are important. In one installation, by the use of the disk mill, the coverage of the expensive top liner was so improved that the operators were able to reduce the weight of this high cost ply by one-third.

Miscellaneous Applications

In addition to the above sketchily mentioned applications in the more usual pulp and paper mills, revolving disk refiners have found profitable application and acceptance in the production of coarser fibrous sheets. In the straw board mills, revolving disk mills are used in preparing furnish from ceral straw, flax straw, and soy bean straw for the production of corrugating board. In saturating felt operations, disk refiners are successfully employed in preparing the raw material from a variety of sources such as raw wood, steamed wood, high yield semichemical pulp, and asplund fiber. Similarly, in wallboard plants, including those manufacturing the dense type of board, disk refiners are widely used in preparing a wide variety of waste fibrous materials for the manufacture of the finished product. These waste materials include bagasse and straw, sawmill waste, planer mill shavings, in

fact any fibrous material that can be had in quantity at a low price.

Conclusion

To summarize, beating and refining continue to be very much of an art but the procedures are yielding to technology. Beaters and jordans continue to be the traditional equipment for refining procedures but revolving disk mills seem to have entered the field permanently. Such disk refiners have pre-empted a great many fringe operations where jordans have been unsuccessful and are now invading the entrenched fields of the traditional equipment. Most important, changing economy demands lower cost of production and especially better wood utilization and this is the field in which disk refiners have shown greatest merit.

Stock Preparation

Fred Herbolzheimer Jr.[1]

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Introduction

How can stock preparation be defined and what does it cover? A generally acceptable definition might include those parts of the manufacturing process where physical and chemical adjustments are undertaken to make pulp suitable for forming a special paper on a paper machine. This would encompass the manipulation of pulp from its arrival at the mill up to and including stock storage in the machine chest, prior to using it on a paper machine. In a non-integrated mill this would chronologically include the following steps:

1. Bulk Handling and Storage
2. Fiberizing, getting the fiber into suspension
3. Beating
4. Blending of Additives
5. Refining
6. Stock Storage
7. Dirt Removal
8. Broke Utilization (Blending and Metering)
9. Metering and Consistency Control

There are other duties in any specific mill, but those listed above are generally the main operations of the Stock Preparation Department.

The two major functions normally associated with stock preparation are beating and refining. Beating could be defined as a blending of various raw materials in a water suspension, and by mechanical action developing specific properties of the fiber which help determine the final product. Refining is a further mechanical treatment under more exacting conditions which contributes to fiber separation.

Before discussing the various pulping processes, the basic raw materials should be defined. It would be opportune to review the popular conception of the cellulose fiber and present some theories as to what happens to this fiber during the beating and refining phases.

It has been established that the cellulose molecule is made up of somewhere between 200 to 1500 glucose anhydride units grouped in a long chain molecule. A detailed review of molecular structure has been presented earlier in this volume. It is further suggested that groups of molecules, approximately 60 in number, form another group known as *micelles*. This theory is somewhat speculative as micelles are not visible under a microscope, but assuming they are present, groups of molecules making up micelles will then combine to form what is called fusiform bodies. These are tiny units that are visible under the microscope. They are slender and have pointed ends. The fusiform bodies in turn have a tendency to overlap at the ends and form a long, slender diameter particle known as a fibril. *Figure 1* indicates how the pointed ends join to form fibril of practically a constant diameter. Now these fibrils help to form the cellulose fiber by wrapping themselves around the core, or lumen, which is roughly similar to a straw. The fibrils laying near the center have a tendency to align themselves along the longitudinal axis, at an angle of ten to thirty degrees. As this fiber is built up, the fibrils will become more and more perpendicular to the axis until at the end they are travelling at right angles, wrapping themselves around the axis. On the outside of this fiber there is a very tough water resistant layer of wall known as cambium layer. The fiber has fundamentally a crystalline structure of the cellulose molecules, with some amorphous areas.

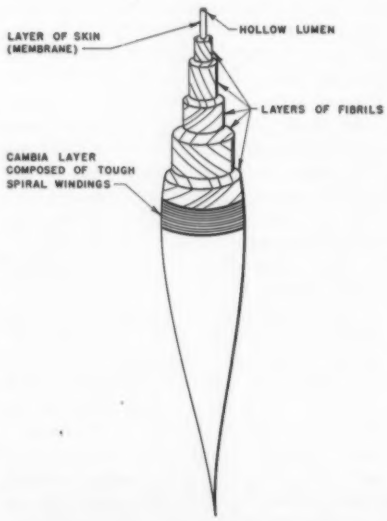

Figure 1—Schematic of Cellulose Fiber

The above is a popular theory of a cellulose fiber make-up. It may, or it may not, be strictly correct. With this picture of the fiber in mind, however, it is possible to describe what happens to the fiber during beating.

Theory of Beating

By way of background, paper was originally made by Egyptians and Chinese from the inner bark of trees. Beating of this bark was not neces-

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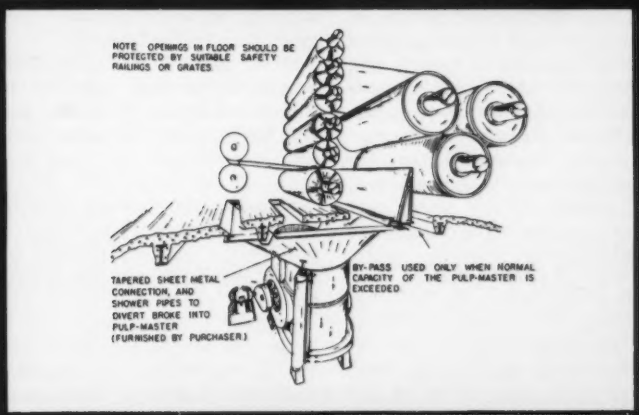
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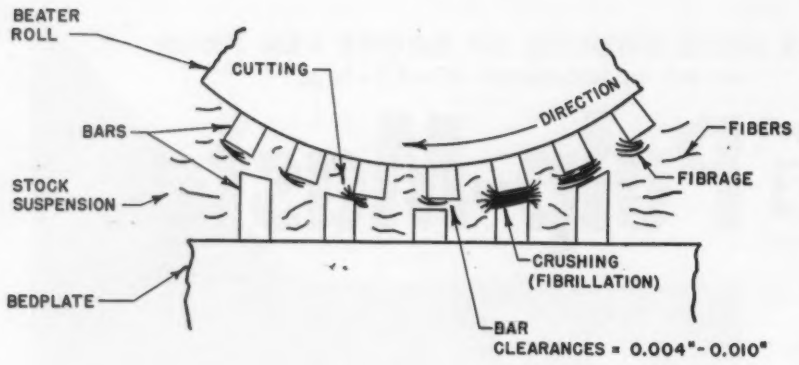

ELEVATION

Figure 2—Bar Action on Fiber During Beating

sary. These fibers were in such physical state that paper could be formed immediately. However, this was so impractical and so slow a process that it was necessary to find some method of preparing, or beating, the fibers.

Actually the first developments were entirely mechanical. The fiber was macerated by hitting with rods or by crushing in crude stamping mills. However, with the coming of the machine age, the middle of the eighteenth century, a beater was developed in Holland which is fundamentally the Hollander type beater engine in use today. In recent years it has been found that some types of paper can be made without beating. The old adage that "paper is made in the beater" is not entirely correct today but fiber preparation certainly is a step to be considered. It may be that beating has gone into the background in recent years because of high speed operation but is still a fundamental process and some work on the fibers must be done in the manufacture of any type paper.

Now to discuss the effect on the raw material during beating. There are several concepts concerning this phase. The most popular theory states that beating does nothing more than work mechanically on the durable water-resistant wall of the cellulose fiber, breaking that wall down, and allowing the inner fibrils to be exposed. These fibrils are receptive to water and consequently will swell and expand. Portions of the initial fiber break off and form smaller fibers. This exposure of the inner fiber is known as fibrillation, as advanced originally by W. Boyd Campbell of Canada.

The work is actually done by mechanically rupturing the fiber; initially by external pressure on the outer wall, then secondly after the wall is broken by water being drawn into the voids between the inner fibrils thus forcing them apart. Unlike the original round, smooth fiber, the beating produces a thinner ribbon-like structure. Other times a portion of a fibril may just break off entirely. It is suggested that these small particles going into solution improves the strength properties of the stock. Therefore, it can be said that beating ruptures the cell wall, and exposes many inner fiber fragments, or fibrils. This then is what is meant by fibrillation, and is the major factor in strength development.

Transverse cutting or shortening of the fiber also results from beating. Fundamentally beating is the intimate movement of metal bars through a water-pulp suspension and to get the desired fibrillation effect, there is fiber shortening. Generally transverse cutting is not desirable because it appreciably destroys the inherent strength in the fiber itself by making it shorter, although in some specific papers this type of beating is wanted.

Reduction of the cell wall thickness is an obvious result of beating. The firm cell wall is broken and there will be a gradual shrinkage in diameter as fibrils are removed from the fiber. At the same time, there is an increase in the exposed surface area. Campbell states that new surfaces are not created but only existing surfaces in the fiber itself are exposed by opening up the cell wall.

Finally, the last effect of beating to be discussed is known as *hydration*. We do not think of hydration in a strict chemical sense, but rather as the phenomenon of having water intimately associated with the fiber although not actually combined. It has been said that the fiber becomes wet or "wetted" and this is perhaps a better description. The stock flows slower, and is slippery, or greasy, to the touch. There is some true hydration, normally about three per cent of the total water.

Hydration is the effect that makes the fiber more resistant to drainage on a machine as the new surfaces exposed offer increased friction to the flow of water across them. It is something that must be considered. Stock preparation combines water and fiber and then the paper machine removes the water and forms a sheet of paper. Therefore, in commercial operation hydration, or wetness, plays a major role on how the sheet will form on the wire, and what its first qualities will be.

The action of beating on the fiber can best be explained by examining *Figure 2*. The schematic drawing represents the bottom of a beater containing a pulp suspension through which the roll is rotating. The bars, or knives, on this roll almost contact the knives in the bedplate. Bundles of fiber are present throughout the suspension, and have a tendency to collect on the leading edge of a moving bar. If these fiber bundles on the leading edge do not have a chance to realign themselves, but remain perpendicular to the long axis of the bar it is obvious that fibers will be cut when the bundle contacts the edge of a bar in the bedplate. This is how fiber shortening or transverse cutting occurs. If the fibers have an opportunity to align themselves with the working surface of the bar, they will have a tendency to be crushed causing more fibrillation, more hydration, reduction of cell wall thickness, and less of transverse cutting.

The effects of beating on the fiber have been set forth. The next logical step is to explain how these effects improve the tensile strength and increase density in the final sheet. It was stated previously that fibrillation increases surface area, and that water enters the capillary voids between the inner fibrils. As beating progresses more surface is exposed, and there is less space between the newly exposed surface. When the pulp is dried tremendous surface tension (air to liquid films) pulls the surfaces tightly together. Obviously the magnitude of the attracion is determined by the degree of beating as surface tension is inversely proportioned to the diameter of the capillary passage.

It has been stated that the radius of the capillary passage is approximately equivalent to fiber diameter. If this capillary action increases density by pulling fibers tightly together, then what increases tensile strength? What holds these surfaces together? The theory of cellulose bonding presented by W. Boyd Campbell explains how the surface could be bound.

To explain cellulose bonding consider a simple saturated sugar solution into which one sugar crystal is

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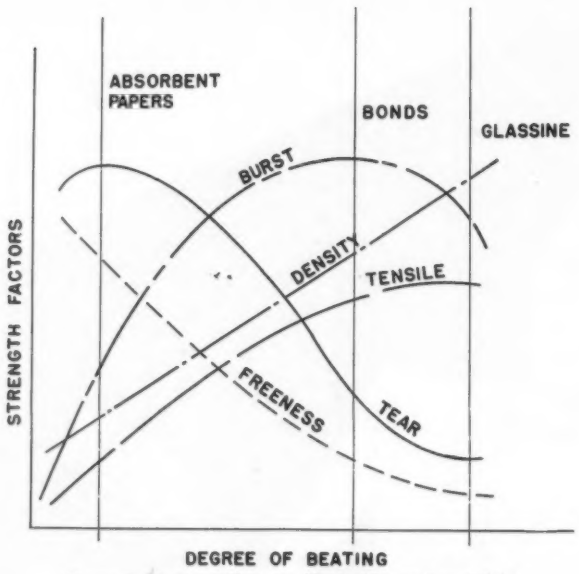


Figure 3—Beating Effects on Physical Properties of Pulp

dropped. If this crystal of sugar is placed in the saturated solution, tremendous surface activity results, but the weight of the original added crystal remains unchanged. The molecules of sugar in solution deposit on the crystal (crystallization) at the same rate that molecules in the crystal enter the water (solution). It is then said that along the surface of the sugar crystal there is a layer of hydrated sugar in constant motion.

Cellulose, being made up of long chain units basically similar in structure to the sugar glucose, might also be assumed to have this surface activity. However, due to the chain length of these sugar glucose groups, it would be an impossible requirement for the entire chain to go into solution at the same instant. At one point, thermal vibrations forcing melocules into solution might be aiding others to deposit back into the crystal surface. There would then be a thin layer of a saturated solution of cellulose covering the entire surface of the exposed fiber. This layer could then be termed a surface layer of true hydrated cellulose. It must be remembered that this is only a thin layer at the surface and as previously mentioned, only three per cent of the total water in a stock suspension is hydrated.

In review, it could be assumed from the above that all cellulose in contact with water has a surface layer of hydrated cellulose. This would explain how the additional strength results from beating. More surface is exposed, and the surfaces will be closer together. Layers of hydrated cellulose on all surfaces would mingle in close proximity to each other. Upon drying, the water is evaporated and cellulose molecules in solution would go to any nearby surface and thereby create one continuous structure. To lend emphasis to this theory of bonding by a hydrated layer at the surface it has been established that strength develops by beating pulp in water, not in any other liquid.

In summary, beating increases strength and density in the final sheet through capillary action which results in pulling surfaces together. It promotes the bonding of fibers by creating a hydrated cellulose layer on all surfaces.

Now to explain how beating determines properties in the sheet of paper. The primary result in is increased strength. This is developed through fibrillation and through the end effect of increased surface area and cellulose bonding. Beating increases the density of the sheet because it makes the fibers shorter, more compact. Of course, a dense sheet will be less porous. It will normally be stronger and it is said to have rattle. An example is a highly beaten bond paper. It is crisp and stiff due to its high density and if the sheet is shaken it will actually rattle. However, a sheet of absorbent paper such as tissue will not do this because it is beaten to a lesser degree.

Of course, as density increases the surface area is reduced due to shrinkage. In other words, the more stock is beaten the shorter the sheet will be on the machine. An example of this is the manufacture of towel and tissue papers. As towel stock is beaten more, developed more, it shrinks three times as much in width as does tissue on the paper machine.

If pulp is beaten to the extreme, the paper becomes transparent. This is a physical phenomenon. That is, as any material is processed to a homogeneous mass it tends to become transparent.

Specific properties in paper are obtained through the use of chemicals added in the beater. The effectiveness of these additives are determined to some extent by beating. Beating normally increases filler retention. For any given amount of size and alum it increases the sizing characteristics of the paper. Also for any given amount of dye beating will produce a more intensely colored sheet. It does not increase the capacity for retention of the dye, but does seem to make dye more efficient.

One thing that should be mentioned is that no chemical change results from beating itself. It has been proven that beating is a mechanical phenomenon, and causes very little chemical change in the fibers.

Beating affects the softness of paper. This is often a desirable property. Absorbency and softness are usually required together in the same paper. This means beating must be limited to prevent over development of the fiber which would result in a dense, stiff sheet. Absorbent, soft papers then cannot be as strong as well beaten sheet. This illustrates one of the many compromises necessary in stock preparation.

Figure 3 shows what happens to the physical properties of the stock as it is beaten. Tensile strength and burst strength develop progressively with beating. However, a point is reached where more cutting than fibrillation occurs, and then burst drops off appreciably and tensile strength will diminish gradually.

Resistance to tearing is a strength factor that is the antithesis of burst and tensile. Tear will increase slightly at the start of beating then continually decrease as beating progresses. How is this explained? Tensile and burst are developed because of increased cohesion of similar surfaces. Upon bursting a sheet of paper, or testing the tensile strength by pulling it apart, fiber to fiber strength characteristics are measuring. However, tear is something else. When a sheet of paper is torn it is cut right across the fiber. This is a shearing action and is essentially a measure of inherent fiber strength. The beating process reduces this inherent strength within the fiber, by breaking the hard cell wall, and splitting off some of the inner fibers, without too much degradation of the fiber itself, resulting in increased tear resistance but the effect of beating is soon demonstrated by decreasing tearing strength.

Density and shrinkage will increase proportionally with beating. Freeness is a measure of the drainage of a fiber suspension, or actually its abilities to release water. Freeness will decrease during beating due to more surface area being exposed. This additional area provides more friction thus slowing the flow of water over the fibers. Freeness is a common test used to quickly measure the degree of beating.

Beating Equipment

It would be well to mention some of the beating equipment and its development. For 150 years beating has been done by a basically Hollander type beater. This is schematically shown in *Figure 4*. Water pulp suspension is circulated around the two channels and pushed beneath the roll, up over the backfall, and then around the other channel. The backfall gives the stock a hydrostatic head so that it can travel back to the beater roll.

At the base of the backfall there is a bedplate containing bars. Bars are also placed around the roll parallel to the axis of the roll. The stock is forced between the sets of bars and pushed up over the backfall.

The only part of the beater that accomplishes useful work is that which is realized between the knives of the roll and bed plate. The work required to move the stock around the channels is wasted, except perhaps for providing a soaking period for the pulp, and this is of controversial value.

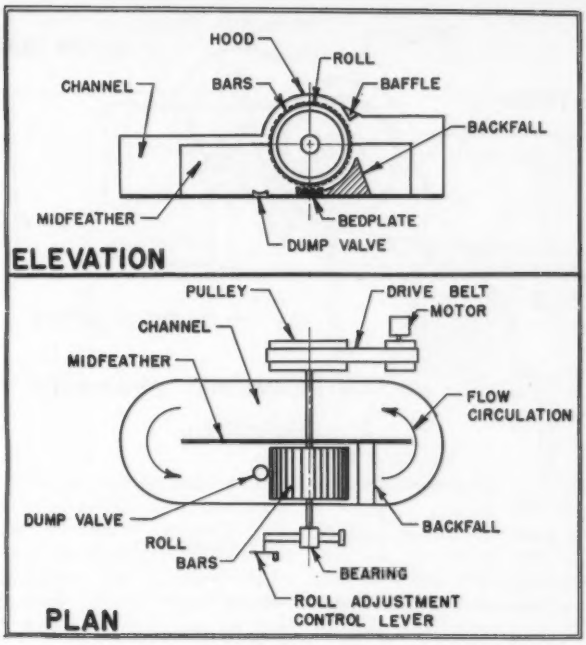
The roll is driven by a motor which is normally connected, and reduced, through a belt or chain drive. The roll pressure against the bedplate is adjustable through various types of lever arms.

To give some idea of the size of beaters the following is of interest:

1. Capacities range from 500 to 3,000 pounds of air-dry pulp per batch.

2. The channels are from three to six feet wide and seven to fifteen feet long including the ends.

3. Roll diameters vary from 60 to 90 inches.



Fiure 4—Schematic of Hollander Beater

4. Roll weights may be from 6000 to 20,000 pounds.

5. The range of operating pressure is 30 to 150 pounds per square inch across the roll.

6. Roll speeds of 100 to 3000 feet per minute, at the periphery of the roll, are commonly used.

7. Power input may be 50 to 200 horsepower and even then only fifty per cent maximum is effective work in crushing the fibers.

8. The bars are from one-fourth to one inch thick.

As a guide, it has been stated the bar thickness should be twice the fiber length but this is seldom followed.

9. Beating times may be 30 minutes to 8 hours.

10. Consistency usually is not over three to five per cent air dry (3000 pounds of pulp and 10,000 gallons of water.)

Advantages of Hollander Beaters:

1. They are simple and low-cost machines, a decided factor in today's high cost replacement picture. They are simple to make and have few fine machine parts. They are easy to duplicate or replace.

2. The beater requires a minimum of maintenance. The bars and wooden spaces called "beater tackle", must be occasionally replaced. These bars must be kept uniformly sharpened and that, plus lubrication, and periodic checks on the drive, completes the maintenance requirements.

3. For the control available, it is easy to operate.

4. They provide fair mixing of additives to the stock.

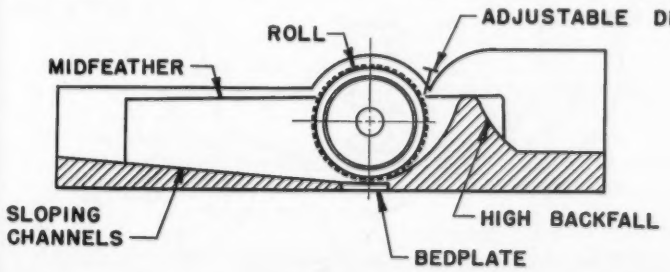
Disadvantages of Hollander Beaters:

1. Extremely high power consumption is required. They are very inefficient. The large roll is used to move the stock around the beater and, of course it is a very inefficient pump.

2. They have low beating capacity for today's high speed operation. While 3,000 pounds of stock may seem to be a substantial quantity, a machine producing 200 tons of paper per day would consume that load in less than ten minutes. Also, it requires a great deal of time to load, and to get the desired pulp qualities. Useful work is only being done while pulp is between the roll and bedplate bars.

3. The controls are crude. Reproducibility is difficult to obtain because of limited controls.

4. They are bulky and require much space. For example, large flywheels are required to reduce motor speeds of 1600 to 3200 revolutions per min-



Fiure 5—Niagara Beater

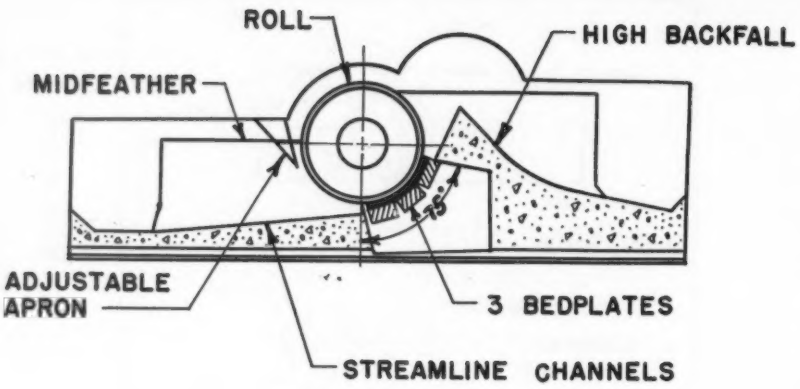


Figure 6—Jones-Bertram Beater

ute down to 60 or 80 revolutions per minute for the roll.

5. Due to poor circulation (called channelling), the stock is not developed uniformly. The stock on the inside of the channels will pass under the roll more frequently than that on the outside.

What has been done to improve the Hollander? All manufacturers have introduced variations to overcome the above five basic disadvantages. An earlier improvement was the Niagara beater, *Figure 5;* this has a higher backfall and more streamline flow. This results in better circulation and higher efficiency as well as operating at a higher consistency.

The Jones-Bertram beater, *Figure 6* is another efficient machine. This has a normal roll but three bedplates are used which are set from the vertical up to about 75 degrees on the backfall. There is a space in between each set of bedplates. It has a high backfall, streamlined channels, and an extra hood so that the stock coming up from the roll goes into this hood and over the backfall. This prevents stock from carrying around the roll, reducing circulation. Another unique feature is a guard in front of the roll to direct the stock toward the bottom of the roll. This beater has gained wide acceptance and according to all reports, has proven satisfactory.

There are numerous other beaters but time will not permit a discussion of each type. The Horne type beater prevents poor circulation, common in the Hollander, and insures good blending. The roll is at one end, rather than in the middle of a channel, making the unit a little more compact than the Hollander. The stock that flows on the inside of one channel passes under the roll, then over the roll and to the outside of the opposite channel. This can be seen in *Figure 5.* The Horne beater then mixes the stock every time it circulates around the tub, but is still inefficient in its use of power.

Two radical departures from the standard Hollander are the Vortex and the Victory beaters. The Vortex, *Figure 7,* is a vertical tub with another vertical tub inside called the stator. In the center, there is a rotating vertical shaft on which is attached helical fins which drive the stock to the bottom of the beater. At the base of the rotating shaft there is a disc to which bars are attached. The base of the stator also contains bars. Both sets of bars are placed radially from the center in a horizontal plane. As the stock reaches the bottom of the tub it flows between the bars, then back to the top of the tub. It is obvious that the flow across the bars is entirely different from that of a Hollander. This Vortex beater increases the bar area for a given charge, improves circulation and by the use of the fins reduces power consumption. It is an easy unit to load as entire bales can be charged directly at the top, which is located normally at the operating floor level.

The Victory beater, *Figure 8,* is unique in that the tub consists of three channels with an agitator at the end of the center passage. Stock is charged into the tub and defibered. Then it is pumped from the tub to a head-box which causes the stock to flow uniformly across the long beater roll. Several rolls may be used in series. This is a high production unit. The rolls are only used to beat the stock as the pump efficiently circulates the stock. The bedplates are adjustable and can be accurately set for proper bar-to-bar clearance. The unit can operate continuously by drawing off some of the stock during recirculation. Also, one beater roll unit may serve several tubs. Advantages claimed for the Victory are high capacity, good control, low power consumption, and flexibility of operation.

There are other beaters used extensively in Europe, which are not too popular in this country today. These include rod mills, ball mills, and kollergangs. They produce extreme hydration with little cutting. If it is absolutely necessary to prevent cutting, these units are effective. The rod mill, for example, is a rotating cylinder containing large, heavy rods. The tumbling action of the rods caused by rotating the cylinder ruptures the fiber. They are extremely noisy and have a very low production rate. They do not lend themselves to today's high speed production requirements.

The equipment used will greatly influence the beating action. Perhaps the most important single factor is the tackle. Variables in the tackle include:

1. Sharpness of the leading edge of the bar.

2. Angle at which the roll bars meet the bedplate bars.

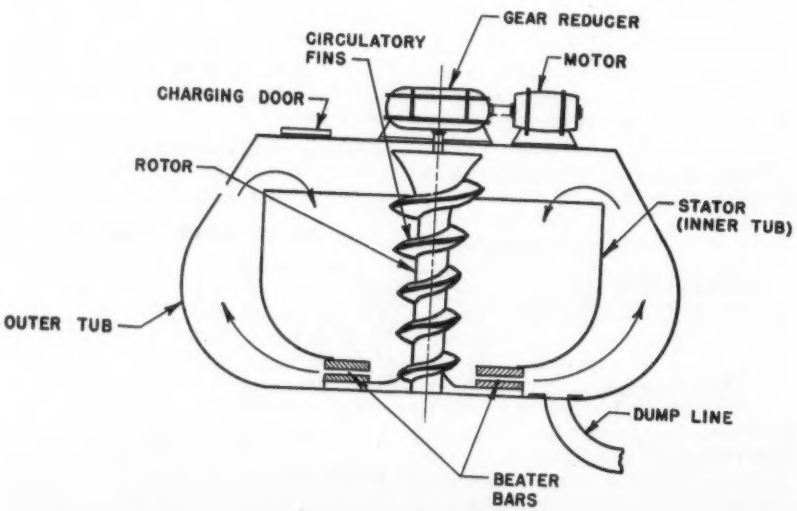


Figure 7—Vortex Beater

3. Number of bars.

4. Width of bars.

5. Pressure between bars. In other words, how much pressure the roll is exerting on the suspension.

6. Materials of construction.

It would be advantageous to discuss materials used to make the bars. Bronze has been used for years but it is susceptible to corrosion. Being a soft material the leading edge tends to become rounded. A rounded edge would seem desirable to prevent excessive cutting, but a soft material tends to round to varying degrees and this results in lack of uniformity from day to day. For a long time steel largely replaced bronze. However, it is susceptible to corrosion and errosion. It is a hard metal, but it has a tendency to blurr. Consequently, today, stainless steel or monel are used for bars. They do not contaminate the pulp and more important they take, and hold, a good edge.

Consistency plays a major role in beating. A low-density stock, in which there is very little fiber for a given volume of water, will permit more fiber-to-bar contact with less fiber-to-fiber contact. This increases fiber cutting while reducing fibrillation and hydration. A high consistency stock will allow more fiber-to-fiber contact and less bar-to-fiber action. This produces increased fibrillation and reduces cutting. While high consistency beating is normally desired, equipment design will limit how heavy a suspension can be processed.

The method by which the pulp was cooked will affect its beating characteristics. Alkaline pulps have a tendency to dissolve out the hemicellulose which has been found to aid in beating. Thus kraft and soda pulps do not have a tendency to hydrate or fibrillate to as high a degree as do sulfite pulps. Sulfite cooking is a milder process, which leaves some of the hemicelluloses and pentosans in the pulp. However, groundwood contains all of these impurities but will not beat. Refining and beating a mechanically made fiber will not appreciably strengthen, or weaken, the final sheet. Obviously, then, groundwood will not fibrillate or hydrate.

Temperature also affects beating. The lower the temperature, the more viscous is the suspenion and the more resistance is offered. The fibers are said to be cushioned. Beating requires work. The stock will beat as this work is expended and the resulting temperature rise is often used as a rough control in beating.

Design of the equipment affects beating. Increasing roll speed increases the number of times any one bar will work on the suspension. However it must be remembered that roll speed is not the only factor affecting the stock circulation rate, bar spacing also affects this rate.

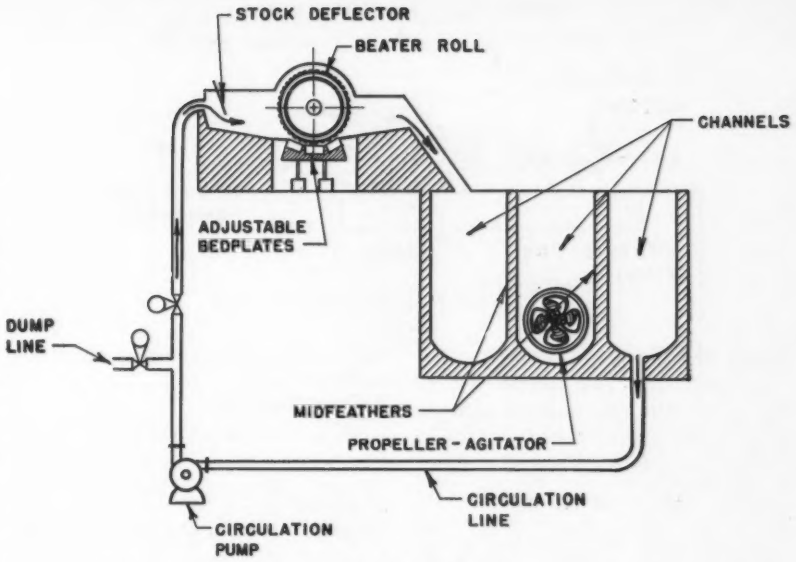


Figure 8—Victory Beater

Foreign ions affect beating. The cellulose, having a negative charge, is affected by the addition of foreign ions. That is very important today when so many special chemicals are added to the beater. Alum, for instance, should not be added during the beating cycle. The positive ions work with the negative ions of the cellulose fiber deterring beating. Alum should always be added near the end of the beating cycle.

How is the beating process controlled? Consistency is the one raw material control. For reproducible results, assuming all equipment variables are maintained at a specific level, the suspension must be at the same density for each and every batch.

The only other operational control is roll setting. This can be accomplished in many ways. It was done originally by manual control. The old beater engineer after years of experience could say, "All right lad, lower the roll two turns", and the assistant then lowered it while the engineer listened and then said, "That's it! leave it there for three and one-half hours." Usually he was correct and the charge had the desired qualities, within broad limits. Nevertheless this method is outmoded in today's technical approach to stock preparation. Improved controls and pulp testing have tended to eliminate this personal approach.

One way to control the work is by measuring the power input. As the stock is beaten input to drive the roll at a definite clearance is reduced. Then for any furnish, roll settings can be made on definite recorded power values.

The roll weight can be measured. By the weight we mean the actual weight of the roll plus the leverage on the roll. The actual pressure on the roll, in pounds per inch of roll width, can be recorded and controlled.

As previously mentioned, freeness of the stock is the easiest and quickest test to determine how beating is progressing. Due to many variables, however, it is strictly an operational test, and for accurate knowledge other physical tests are taken. Freeness is an arbitrary value applied to the stock and for any paper the proper freeness value for the stock going to the paper machine must be determined by experience.

A study of *Figure 3* will show how freeness is affected during beating. Beating progressively reduces pulp freeness. Papers whose stock is comparatively free, such as absorbant papers including tissue, toweling, and blotting, will be only slightly beaten, while strong papers such as bonds will have much lower freeness and will be beaten severely enough to produce optimum strength. Finally, paper whose stock is extremely slow (low freeness) such as glassine, will be beaten long enough to produce a very dense, transparent, and non-porous sheet. Glassine is weaker than most other papers as the fibers have been worked past the optimum fibrillation stage so that they are sufficiently shortened to provide the quality of compactness.

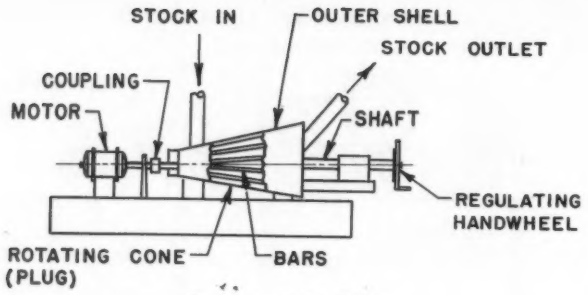


Figure 9—Jordan Refiner

Theory of Refining

Refining is a continuation of the beating process, under more accurate control. Normally refining is used to brush out the remaining fiber bundles, or groups of unbeaten fibers. These bundles result from the defects of a beater as listed above. They are always present. Hydration can be increased in a refiner. This is seldom attempted, however, due to close bar-to-bar contact in a refiner. A refiner does cut the fiber easily. Normally, the old technique was to hydrate the fiber in the beater and cut it in the refiner. The fiber is cut to control drainage on the wet-end of the paper machine. While the refiner is used in stock preparation the machine tender must use at least one refiner to control drainage and sheet qualities, particularly formation.

In the past, refining normally shortened the fiber. However, today this is avoided as much as possible. Modern refining now improves strength and formation in the sheet with little loss of fiber lengh. Drainage can be largely controlled through improved wet-end equipment and selection of proper furnish. Stock preparation today attempts to build something into the fiber, rather than to destroy it. Again, beating and refining are closely related in the modern mill, and one or the other may be eliminated.

In considering refining, the same principles and effects discussed in beating apply, but to different degrees. Refining is a more intimate process. It is a more controllable process. Refiners have gained in popularity over beaters because:

1. They are versatile.
2. They are accurate.
3. They are easy to control.
4. They have a high through-put (capacity).
5. They are comparatively inexpensive.
6. They have a minimum space demand.
7. They permit a continuous operation.
8. They are reasonable in power demand. More work is done on the fibers and less in pumping the stock.

Refining Equipment

There are two definite groups of refiners; the conical (jordan) type, and the disc type. The jordan type was developed about 100 years ago. It is essentially a solid, conical plug within a conical shell as shown in *Figure 9*. The plug rotates at 300 to 550 revolutions per minute. Peripheral speed is 2300 to 4500 feet per minute at the larger end. The stock enters the smaller end, passing between the plug and the shell and then discharging at the large end. On the working surfaces of both plug and shell, bars are placed parallel to the longitudinal axis. The plug shaft runs in bearings, the one at the larger end being a thrust bearing. This bearing is connected to a handwheel which positions the plug horizontally, controlling plug and shell clearance. This simulates lowering the roll in a beater. There are more bars at the larger end to equalize wear and maintain fit between plug and shell. The stock generally goes through the jordan at a consistency of three per cent.

Some of the developments in recent years on conical refiners have been:

1. To make a heavier, more substantial piece of equipment. To utilize better bearings, couplings, and drives.
2. To provide additional adjustments to give better, more accurate control.
3. To increase speed and power. Speed is only important in relation to power imput.
4. To increase versatility of bar arrangement. Bar arrangement can increase hydration or cutting, whichever is desirable. Channeling and deadspots have been eliminated by proper bar design.

Many jordan-tipe refiners have been developed to produce specific end results. Among these are Claflins, Hydrafiners the Jones high-speed refiner, the Weiner refiner, and the Morden Stockmaker.

The Claflin is a short, wide-angle jordan. It is normally used for defiberizing fiber bundles, and when it is desired to minimize cutting. The high speed refiners (Jones and Weiner) are comparatively small pieces of equipment. They operate at 900 to 1800 revolutions per minute but as the plug diameters are small the peripheral speed is very high. This high speed has a centrifugal effect and helps to break up dirt and fiber bundles into very small particles. They have been useful in mills that want to do some brushing or to break up dirt into minute particles.

The Hydrafiner is a rugged, large conical refiner. It is a high speed unit with wide bars. There is an impeller on the shaft near the stock inlet (small end). This impeller pumps stock into the small end of the working zone thus eliminating deadspots. High consistency stock must be used for best results. This high consistency, plus wide bars and special bar arrangement, produces maximum fibrillation with little fiber shortening. The manufacturer suggests that a Hydrafiner and cutting jordan be used in series for flexibility and maximum fiber development.

The Morden Stockmaker is a unique conical refiner. It has a hollow rather than the regular solid plug. Stock enters at the bottom of the small end, passes through the plug to the large end, then between plug and shell, discharging at the top of the small end. It is given impetus by vanes inside the plug. The bar arrangement allows for extreme hydration and little cutting. The recirculation within this piece of equipment can be controlled.

The disc type refiners are a radical departure from the standard conical refiner and somewhat resemble an attrition mill. In place of a shell and plug, two vertical discs are used, either or both of which may be rotating. Stock enters through a hollow arch and passes vertically betwen the discs to the periphery by centrifugal force, and then is discharged. This is shown in *Figure 10*. Each disc is fitted with removable plates containing a variety of working surfaces. The clearance between discs can be accurately controlled due to the massive construction and fine adjustments available. This is necessary as a small adjustment reduces clearance to a greater extent than in a conical unit whose bars are not in the plane where the movement is made. Disc refiners are versatile in that new plates can be installed quickly to change refining qualities.

The controls on a disc refiner are the same as for other beating or refining equipment. The discs are adjusted to control surface-to-surface clearance. However, through-put can be regulated without disturbing disc clearance by manipulation of exter-

nally controlled orifices at the periphery of either, or both, discs.

The three main factors affecting refining are clearance between discs, the speed of the discs and type of working surface.

Popular disc refiners in service today are the Sutherland, Sprout-Waldron, and the Bauer Fibrator. The Sutherland, and Sprout-Waldron have only one revolving disc. The Bauer produces a terrific shearing force on the stock as both discs are driven, but rotate in opposite directions. In disc refining, the action on the stock differs from that done in conical refiners due to the movement of stock by centrifugal action across the discs which are rotating at right angles to this flow. This tends to shear the fiber, minimize cutting and increase fibrillation.

In refining, consistency is most important because of intimate bar-to-bar contact. If cutting is important, stock density is maintained at three per cent. If maximum hydration is desired, the stock is at six to eight per cent consistency. Other important controls are surface clearance, rotating speed of discs, and power input. At equal capacity and power input, a higher speed unit will provide more fibrillation with less cutting. To get higher sped at equal power input, clearance must be increased allowing more fiber-to-fiber contact.

The Stock Preparation Department

We have completed the formal portion of the discussion. However, as prospective production men it would be advantageous to informally mention some of the operational considerations that are frequently more important to smooth production than the theory of beating and refining. I present these for your consideration believing them to be important factors that seldom appear in the literature.

What do we generally have to deal with in stock preparation? First there is bulk handling and storage. What is important here? In a non-integrated mill of any size where pulp is received in bale form, mechanization is the answer to today's high labor cost. Lift trucks, pallets, cranes, and conveyors are essential, and quickly pay off if properly installed. However, the wrong piece of mechanized equipment, in addition to aggravating the men, will actually increase costs due to additional capitalization and lower work efficiency. Mechanized equipment must be effectively sold to the men as a method of easing their work load. Proper personnel training is essential in this sales promotion. An aggressive preventative maintenance program will keep this equipment operating continuously.

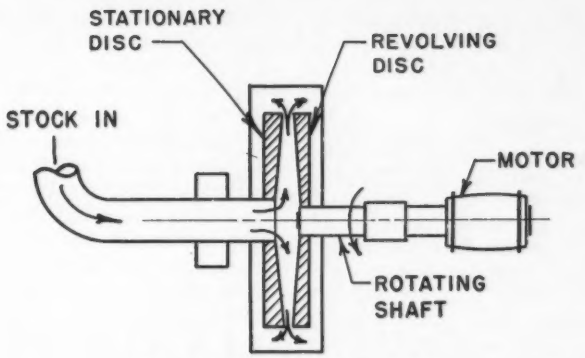


Figure 10—Schematic of Disc Refiner

For proper pulp storage there must be a larger area to allow shipments to be stored by lots, with sufficient room to maneuver these lots quickly and easily. Each lot must be properly identified and stored in a clean location. Pulp should be covered if it is warehoused out of doors. It is important to rotate lots, using the oldest first. It is desirable to turn over the inventory systematically to prevent dirt contamination and to deter fungi. The final factor in handling and storage is to work closely with the technical department. This group will normally test all incoming pulp shipments, and schedule the lots to be processed. For your own information, keep a record of specific pulp properties as well as variations from lot to lot. This information is helpful in solving production problems.

Let us go to fiberizing, which is getting the solid pulp into a water suspension. It is not beating. Beating develops specific properties in the fiber. That is one clear distinction often overlooked. Fiberizing is a breaking, pulping, or disintegrating of the dried fiber into a uniform suspension. Here again the right equipment will pay off by reduced operating costs. A rough estimate of work required in fiberizing equipment will run anywhere from 0.5 to 20 horsepower per ton per day. However, new machines should not demand more than one or two horsepower per ton per day for fiberizing alone. This is relatively low compared to a beater which takes around 20 to 40 horsepower per ton per day.

What equipment is available for fiberizing? A regular Hollander beater with special tackle can be used. That same beater should not be used for further beating unless the mill is small and additional equipment is not justified. One reason for this is that a beater must be charged slowly so as not to abuse the carefully sharpened bar surfaces, thus destroying accurate control of the beating process.

A breaker beater may be used but the rolls on these special Hollanders are more massive, and fitted with heavier bars, than those in a normal beater. Vortex beaters, as mentioned before, can be used as a compromise in a small mill between beating and refining. Because of rugged construction and improved design, they seem to lend themselves to both fiberizing and beating. Other satisfactory pieces of equipment for fiberizing that are readily available are the "Hydrapulper," the "Pulpmaster," the "Fibrepulper," and the "Dynopulper." Generally these are large tubs, or chests, equipped with a motor driven propeller agitator which will throw the stock about at a high rate of circulation. This rapid circulation produces much turbulence which tends to separate fiber bundles into a uniform suspension, with little fiber shorening. Another efficient fiberizer is a vertical breaker chest. This is a rectangular chest containing stubby, propeller-type agitators. These breakers have been used for a number of years with wonderful success. Stock consistency is usually limited to 35% or lower for maximum defibering. This may restrict their application if high-density refining is necessary. They require little maintenance, are quickly loaded, and power demand is exceedingly low.

Following are some basic questions to be asked about the beating phase:

1. Is the furnish properly loaded?

2. Is the furnish water properly metered? Fresh water is seldom used as, normally, excess white water from the paper machines is available.

3. Is there sufficient water available at all times? Does its consumption remain constant?

4. Is the proper information on procedures passed on from shift to shift, thereby insuring steady operation?

5. Are the various furnish components compatible? What is the "rate of response" of each pulp in the furnish? Some pulps will beat quicker than others. Usually any furnish is a com-

promise. Various pulps are blended to yield the desired end qualities at the lowest cost. Must these pulps be beaten separately, because of extremes in their "rate of response"?

6. Are beaters necessary? Can modern refiners and efficient fiberizers eliminate the beater in the operation?

7. Is the right beater being used? Have various beaters been studied for special needs? How are beaters compared? Too often, they are sold on glowing reports from adjacent mills, which may have operations entirely different from those in your own mill.

Vickery, in an article on stock preparation equipment presented a formula that contained five factors in selecting a beater.

First, there is cutting, but how is it to be measured? An arbitrary calculation that gave inch cuts per minute was developed by multiplying the number of bars in the roll and bedplate times the length of the bars and the revolutions per minute. Secondly, the number of roll bars times their width, and the number of bedplate bars times their width are multiplied by the length and revolutions per minute. The result was defined as the "wetting effect," or the square inches per minute of beating surface. It is then possible to ascertain if the beater is primarily cutting or hydrating by comparing these two results. This is all very theoretical, but illustrates one method of analytically measuring beaters.

The third factor is the available contact pressure. This is something that can be easily determined.

The fourth factor is the surface speed of the roll.

The fifth is the power consumed. Here it must be determined what portion of the power is used for useful work and what portion is used to drive the roll and circulate the stock.

Then the cutting to hydrating ratio is analyzed in conjunction with speed, pressure, and power. While only arbitrary results are obtained, definite specifications can be established for any beater.

The addition of the right chemicals at the right time must be continually scrutinized. Here we may consider the following:

1. Are the right additives being used? Are they stored, handled, and measured properly and efficiently?

2. Are they added in proper sequence at the right location in the process?

3. Are they performing properly? Should the quantity be changed? Should substitutes be tried?

4. What additives will aid operations? Normally chemicals are used to enhance sheet properties. However, many additives can help do a specific job along the production line. Deflocculating agents, for example, have become popular, to aid sheet formation.

5. Can any chemicals be eliminated? Many times a chemical is added for a specific condition no longer present.

Questions pertaining to refining might include the following:

1. Should there be several refiners? Should they be run in parallel or in series to get the best results?

2. Is this the right refiner for the job?

3. Does the refiner have the proper tackle and is it in good condition?

4. Are we taking the right stock tests? Do they tell us what we want to know? Do the tests indicate what is wrong when problems arise?

Proper storage and blending is often overlooked. Are the chests properly designed to insure good blending and circulation? Poor blending results in stratification and/or channeling of the stock. Stratification refers to layers of pulp building up in the chest as old stock is removed from the bottom while new stock enters at the top. Channeling refers to passage of stock, in constant flow, surrounded by static stock that remains in the chest indefinitely. How much storage is necessary? If a breakdown occurs in the beater room, are the chests large enough to prevent the machine from running out of stock? At the same time, are the chests small enough to prevent rapid furnish changes for new orders? Is the agitator sufficient for good blending? Does the agitator require excessive power to do the job? Are the chests and agitator constructed of the proper materials? Corrosion and erosion of exposed surfaces must be minimized. Are rust or concrete particles contaminating the stock? Does slime form readily in the chests? Tile, monel, stainless steel, and resistant linings, are essential in good chests today. Wood and cement are seldom used. Agitators are often made of stainless steel or are rubber-covered. Finally, is the stock at the proper consistency? Storage capacity can be increased by raising the consistency, providing adequate circulation is maintained.

The selection of good materials of construction yields big dividends when purchasing pumps and pipes. Today cast iron pipes are usually rubber lined or coated with a phenolic resin to prevent corrosion and contamination of the stock. Stainless steel, monel and transite pipe (a combination of cement and asbestos) are use dextensively. Transite has a tendency to shatter and crack. It cannot be used for acid solutions below a pH of 4.0, or for liquids whose temperature is above 170 degrees Fahrenheit. Nevertheless, for general stock conditions it has been very successful. While expensive to install, it requires little maintenance and remains clean indefinitely. It is necessary that the pipe size be right to permit a satisfactory linear flow rate at maximum output.

Stand-by pumps should be available at critical locations to insure continuity of operation. It is important to select the proper characteristics of a new pump. Future requirements must be considered when a new pump is installed. However, over-rating a new pump is as dangerous as under rating, since a pump too large for the job will require a great deal of maintenance.

There are two major factors in dirt control. First, do not let dirt get into the mill. Buy pulp by specifications, and limit the dirt count by contract. Naturally, that depends on economic conditions and pulp availability. This procedure will eliminate about 80 percent of the dirt in the sheet. Most of the dirt comes with the stock from the pulping operation due to ineffective screening. The other source of dirt is in the mill itself. That is why clean mills are essential to a clean product.

There are many types of dirt removal equipment. They are usually installed at the paper machine, not in the stock preparation department. The reason for this is to remove the dirt just prior to making the paper. The stock preparation department can help in dirt control by keeping their areas clean and storing pulp in sheltered locations.

Broke utilization is perhaps the biggest control problem in stock preparation. It must be metered accurately. It has to be handled effeciently. It must be available as needed. Broke beaters or pulpers should be installed where the broke is made. Broke is nothing but unsaleable paper. It is good pulp and must be reused. Where is the best place to let it enter the system? This question must be satisfactorily answered if broke utilization is to be properly carried out. Generally, when broke is rehandled 10 percent of it is lost in sweepings and waste.

Consistency and metering controls must be carefully studied. The most important factor is good preventative maintenance on this equipment to insure continuous and accurate results. A small error in regulation quickly causes trouble throughout the mill.

Conclusion

In conclusion there are four points that you as potential supervisors should consider:

1. The basic rule in stock preparation is to do a quality job. Stock preparation is an additive process, not a subtractive one. The fiber must not be excessively degraded.

2. The problems and working conditions of your men must receive careful and continual attention. Individuals must operate all this modern equipment that has been discussed, and their attitude and skill determines whether or not the operation will be successful. Analyze the men to see which of them will develop into leaders. Who is willing to assume responsibilities? Who thinks clearly and concisely, particularly during difficult periods?

3. You must be cost conscious. Establish budgets for both maintenance and operations and stand by them. See that they are reasonable and realistic.

4. Be aggressive! Try new ideas. Do not accept something because it has been in the mill for ten or fifteen years.

Fillers and Loading

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Introduction

With the exception of certain specialty grades such as filter, absorbent, and most blotting, all papers contain materials other than fibers. One of the most common practices, referred to in mill parlance as "loading," consists of the addition of mineral pigments to the sheet. By filling the inter-fiber voids, the mineral gives body to the paper and produces a smoother, more dense sheet upon supercalendering.

In order to give you some idea as to the extent to which fillers are employed in the paper industry, the Bureau of Mines Minerals Handbook lists figures for one of our most common, clay. During late years, paper production has consumed this material at an approximate average rate of 400,000 tons per year. Even this impressive figure is misleading when you consider the fact that the use of coating clay has grown to similar proportions, roughly 450,000 tons per year, with much of it returned to the paper furnish as filler in the form of broke, rejects, or as a raw material for the manufacture of paperboard. The latter use consists of coated papers employed as top liner fiber for the board industry.

Use of Fillers

Several factors influence the use of filler in a paper mill:

1. In order to enhance the sales appeal of a sheet, certain fillers may be necessary to improve finish and impart to the sheet a smoothness or "feel" so necessary to sales value.

2. Since fillers are generally whiter than the cellulose fibers, they are used to improve color. They also provide a simple means of controlling this important quality specification.

3. Fillers improve printability by presenting a smoother, more receptive surface to the ink applied. Due to their inertness they also give a sheet greater dimensional stability, an important factor in pressrooms not equipped with constant temperature and humidity control where poor register on the press is a problem.

4. The proper selection of a filler will improve the opacity of such items as writing and printing papers when there exists the problem of "see-through."

5. Without impairing the quality of most papers, fillers offer a wide opportunity for reducing costs. Today, with the price gap between filler and fiber steadily widening, the proper selection and use of a filler can be an important means of meeting competition.

A choice of filler will naturally depend on the best possible combination of the above mentioned factors. In the last analysis, there is no established procedure which tells the papermaker what filler is best suited to a particular mill or grade. Rather, a series of trial runs is usually necessary in order to determine what filler will do the job at the least possible cost.

Testing of Fillers

There are several tests made on the fillers which may be used in making a selection:

1. *Brightness* is generally measured as percent reflectance on a G.E. Reflection Meter in terms of magnesium carbonate. The preparation of the sample is important if reproducible results are to be obtained. The moisture content, degree of pulverization, and degree of compactness of the sample block are important factors. *Tables I (a) and I (b)* show the effect of moisture and degree of pulverization on the final brightness of clay.

For reproducible results, then, the clay sample should be dried at a temperature not over 150 degrees Centigrade to a moisture content not over 1.5 percent. Clays which have been finely pulverized can be tested without further treatment, whereas clays containing agglomerates should be passed through a 200 mesh screen by means of a stiff brush.

TABLE I (a)
Effect of Moisture on Brightness (samples passed through 200 mesh screen)

Percent Moisture	Percent Brightness
8.0	82.1
5.0	83.0
3.0	83.7
1.5	84.1
0	84.2

TABLE I (b)
Effect of Degree of Pulverization on Brightness

Degree of Pulverization	Percent Brightness
Lump clay crushed in mortar	81.5
Lump clay passed through 60 mesh screen	82.1
Lump clay passed through 100 mesh screen	83.3
Lump clay passed through 150 mesh screen	84.1
Lump clay passed through 200 mesh screen	84.2

Figure 1—Screening of the Dried Sample

In compacting the screened clay for testing, a pressure of 50-60 pounds applied to the cylindrically enclosed sample has been found satisfactory to give reproducible results.

Figures 1 through 4 depict the steps involved in the taking of a brightness determination. *Figure 1* — the screening of the dried sample through a 200 mesh screen; *Figure 2* — the transfer to the cylinder; *Figure 3* — the application of measured pressure to the clay sample; *Figure 4* — the final determination on the G.E. meter.

2. *Abrasiveness* is measured by circulating a filler-water slurry through a perforated rubber block which contacts a small section of Fourdrinier wire. Abrasiveness of the sample is recorded in terms of loss of wire weight in milligrams. Testing procedure may vary in different mills, yielding different numerical values, but the relationship between a given set of fillers should hold. The practical papermaker detects abrasion in his stock by viewing the "shine" imparted to his machine wire.

3. *Grit* is usually expressed as the residue failing to pass through a wire of specified mesh, usually 200 and 325 mesh screens. Grit is important in that, in excessive amounts, it is not only detrimental to a smooth sheet but may cause a marring on the final surface or damage to the plates if the sheet is to be printed.

4. *Particle Size* is normally measured as the percentage of particles below two microns and above ten microns. There are various methods of determining particle size, all based on sedimentation principles as expressed by Stokes' law. Particle size distribution may have a direct bearing on retention, a subject which we will handle separately.

5. *Index of Refraction.* The R.I. (refractive index) of cellulose is approximately 1.5. Fillers, being above this, tend to improve opacity of the sheet in direct relationship to their R.I. which in turn is in direct proportion to their cost, other things being equal.

6. *pH.* This determination is usually made by the glass electrode method with great care being exercised if reproducible results are to be had. It is an indication of the type and amount of deflocculant required for optimum dispersion of the pigment in water.

Fillers Commonly Used

Fillers may be natural products such as clay, talc, gypsum, ground limestone (chalk) and diatomaceous earth or manufactured products such as titanium dioxide, zinc sulphide, and precipitated calcium carbonate.

Figure 2—Transfer to the Cylinder

1. Clay

Since clay is the predominant filler in use today, it seems logical to treat it separately. Its economy and versatility of application make it an outstanding raw material in the field of papermaking. Its versatility stems from such characteristics as softness of texture, freedom from harsh impurities, chemical inertness, a desirable brightness, a satisfactory ink absorption, and easy dispersibility in water suspension.

Clay is defined as a disperse system of mineral fragments of hydrated aluminum silicate, of which particles finer than two microns predominate, which is plastic when wet and permanently hard when fired. Kaolin or China Clay is a material derived by the weathering of an aluminous mineral such as feldspar, mica, etc.

Clays occur as residual or primary clays, meaning those found at their original points of formation, or sedimentary or secondary clays, those transported by nature from their original points of formation and deposited in basins. The sedimentary deposits of Georgia and South Carolina furnish approximately 90 percent of the Kaolin produced in the United States.

Previous to 1930, English clays were preferred but as improved methods of refining the domestic clays were developed, the sales balance began to change. Domestic production now accounts for 80 to 85 percent of the clay consumed by the United States.

(a) *Clay Mining* — The mining of clay entails the leasing of land, prospecting, removal of overlying soil, called "overburden," mining, and hauling to the processing plant.

Prospecting for clay represents careful appraisal of a deposit to determine its fitness for use. This is done by drilling test holes which not only serve to secure samples of clay, but also to determine the boundaries of the clay areas. Test holes are bored either by hand augers or by core drilling machines. Hand crews are generally used in shallow overburden or in places inaccessible to the drilling machine. In either case, a hole is bored through the overburden until clay is reached, after which samples representing each foot of clay are withdrawn. *Figure 5* shows a core drilling machine on location and *Figure 6* the removal of the core sample of clay.

Laboratory evaluation of crude samples constitutes an important and extensive phase of prospecting. The core samples are cleaned and the brightness determined on each foot of clay depth. Samples of each hole are then divided into composites ranging from 3 to 8 feet of clay depth and analyzed. A complete record, including outline maps and cross sections, is made for each

Figure 3—Application of Measured Pressure to the Clay Sample

Figure 4—Final Determination of the G. E. Meter

deposit. This information furnishes the clay producer with the economic aspects of his deposits as well as an accurate inventory of the types of crude clays in definite locations within each mine.

The clay depth in Georgia and South Carolina ranges from 5 to 40 feet with the overburden depth from 10 to 60 feet. Stripping of dirt is accomplished by either high-powered mechanical shovels, drag lines, elevating graders, or by tractor and pan. Clay is mined in open pits with mechanical shovels and transplanted to the plant either by trucks, large semi-trailers, or in some cases, narrow-gauge railroads. *Figures 7 and 8* show the removal of overburden in the background with clay being mined by mechanical shovel in the foreground.

(b) *Clay Processing* — The refining of clay is accomplished by two basic methods: 1, dry process or air flotation; and 2, wet process or classification in a water suspension.

In the dry process, the clay is crushed, dried, and then pulverized. The particles of desired fineness are lifted by air currents with the coarser particles being rejected by whizzer type separators. The crude clay is dried from an original 20 to 25 percent moisture to approximately 1 to 2 percent in order to facilitate pulverization. The quality of an airfloated clay is controlled by a careful selection of crudes with desirable brightness and relatively low grit content. Further control during pulverization makes possible the production of a good grade of filler clay.

The wet process makes use of the water separation of particles of desirable size distribution. This is accomplished in large settling tanks, hydroseparators, or by mechanical centrifuges. Water washed filler clays can be produced either by the direct refinement of the crude clay or by recovery of usable coarse clay from residual suspensions resulting from the production of coating clay. The accepted fraction is bleached by chemical means, filtered, and dried to approximately 4 to 6 percent moisture.

Tables II, III, and IV show a typical comparison of various grades of filler clay with respect to particle size distribution, percent grit, and brightness.

Competition between the airfloated and water washed filler grades is considerable. The water washed clay generally being wetter and inherently more dense, can be handled with a minimum of dusting when unloaded in the open. However, in most cases, the

Figure 5—Huber Core Drilling Rig on Location

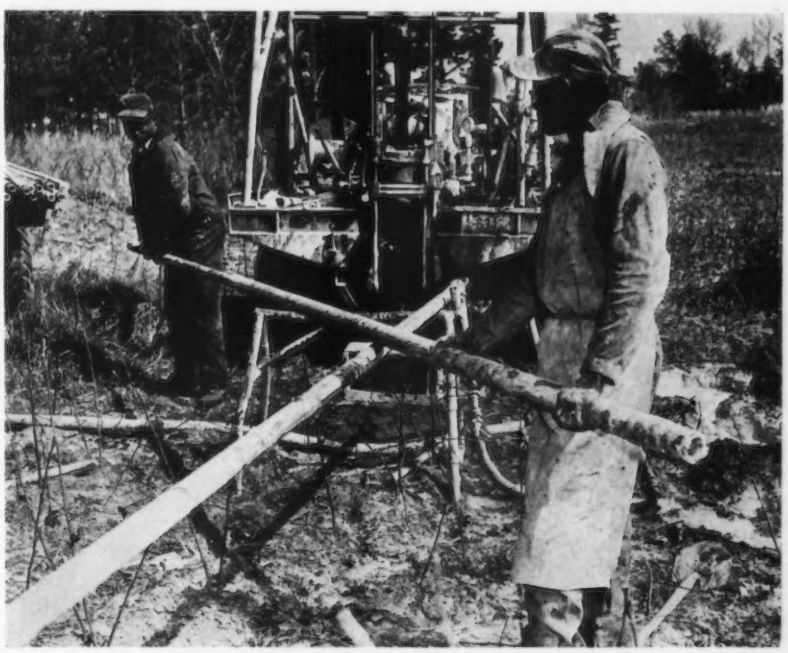

Figure 6—Core Barrel, Core Drilling Rig

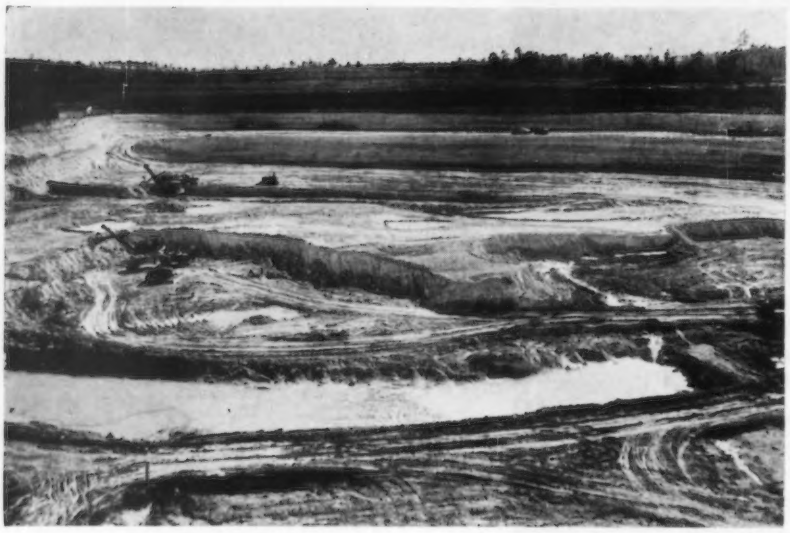

Figure 7—Mining Clay (Shovel Center Left) moving overburden (shovel behind) and more overburden with self loaders above

TABLE II
Particle Size and Distribution of Filler Grade Clays

Micron Dia.	Airfloated Georgia	Airfloated S. Carolina	Water-Washed-Georgia Fine	Water-Washed-Georgia Coarse	English Clay
Above 10	6.0	14.2	4.2	10.0	14.0
5-10	8.6	13.7	10.4	18.1	16.5
4-5	5.0	5.2	4.7	8.1	5.5
3-4	6.7	6.7	6.8	9.8	6.3
2-3	9.9	8.7	9.9	15.6	7.8
1-2	15.8	12.5	15.8	16.0	11.9
0.5-1	18.0	11.3	17.1	16.0	16.0
0.0-0.5	30.0	27.7	31.4	6.5	22.0

TABLE III
Percent Grit of Filler Grade Clays

Screen Size	Airfloated Clays	Water Washed Clays Fine	Water Washed Clays Coarse	English Clay
200 mesh	0.02-0.1	0.01-0.07	0.02-0.10	0.05-0.40
325 mesh	0.20-0.5	0.01-0.25	0.15-0.35	0.10-1.0 plus

Figure 8

two types can be used with equal effect, and for economy reasons the trend appears to be towards the airfloated type.

(c) *Handling and Storage* — Often the handling and storage properties of a clay are prime considerations in making a selection. Clays are shipped in bulk by means of box or hopper cars or in bags, usually of 50 or 100 pound weight.

The present methods of handling bulk clay range from the shovel and wheel barrow method, through car scoops, to the pneumatic system. In the latter method, a flexible hose acts as a huge vacuum cleaner in removing the clay from the car. It then passes through the hose to a filter at which point the clay, with the air removed, is allowed to fall into a silo or bin. The clay is then moved pneumatically from storage to weigh hoppers which feed directly into slurry tanks. A pneumatic system overcomes dust nuisances and can be used to handle clay of practically any physical form. It lessens the unloading time and can often be handled by one man. Also important is the reduction in safety hazards as compared to the older methods of handling clay.

Great strides have also been made in recent years in the handling of bagged clay. Modern materials handling methods include palletized and unit-load shipments with a resultant saving in labor costs and storage space. In some cases, clay is shipped in bleached kraft bags, enabling the beater room operators to throw the bag directly into the beater. The new methods of handling give mobility to inventoried materials and reduce safety hazards.

Clay is slurried at concentrations of from 1.5 to 5.0 pounds per gallon. The tanks are usually of simple construction having agitator arms for mixing. Because of the surface activity exhibited by clays, it is possible to alter the properties of clay-water systems. If small amounts of tetra sodium pyrophosphate, sodium metasilicate, or sodium hexametaphosphate are added to a clay-water mixture normally possessing viscous characteristics, a marked increase in fluidity takes place. Conversely, small amounts of acids, acid salts, or even neutral salts, if added to the fluid mixture cause a return to the viscous condition. Clays are composed of finely divided particles which tend to adsorb ions from the surrounding environment. Depending upon the type and concentration of adsorbed ions, forces of repulsion, or attraction, are created between the particles. When repulsion forces predominate, the system is fluid and is said to be deflocculated, whereas a flocculated or viscous system is created by forces of

attraction. Changes in the physical characteristics of clay-water systems are attributed to this phenomenon of "base exchange."

The deflocculated clay, after thorough mixing, is screened and pumped or run by gravity to storage tanks. Screens of 120 to 200 mesh, usually of the hummer type, are in common use. In maintaining clay in wet storage, it is necessary that sufficient agitation takes place to prevent settling out. Pumping from the bottom to the top of the tank in sufficient volume to form a vortex has been found to be a satisfactory procedure. Paddle-type agitators should move sufficiently fast to prevent any settling.

Normally, 10 to 20 percent clay is added to the sheet although this will vary according to the end use for which the paper is intended. Some special printing papers require as much as 35 percent of filler.

Clay is normally added to the beater as a batch operation but may be added to the beater chest, machine chest, or near the inlet to the paper machine as a continuous process. The main objectives are to give uniform distribution and maximum retention consistent with the demands for sizing qualities of the sheet.

2. Talc

Talc, or agalite, is a magnesium silicate found in Vermont and Northern New York. It is used in papeteries, writing, blotting, and printing papers at a percentage of from 5 to 20 percent. It has a soft, greasy feel and is used mainly to improve the feel and appearance of the sheet.

3. Gypsum

Gypsum, or calcium sulphate, is used in various writing, bond, and specialty grades. It is sold in its original form containing water of crystallization, as burnt gypsum after removal of its water, or as various grades of precipitated calcium sulphate. It is very bright pigment (91-99 G.E.) but coarser than most of the common fillers.

4. Calcium Carbonate

Calcium Carbonate, or ground chalk, is used as a filler in magazine papers. It possesses good brightness but because of its large particle size is not well suited to fine papers. It is frequently water washed or air-floated to free it from impurities.

5. High Strength Pigments

Titanium Dioxide and *Zinc Sulphide* represent the high strength pigments. They were introduced about 1916 in the paint trade where their high opacity in oils is extremely valuable. They are characterized by greater whiteness and brightness, smaller particle size, and definitely higher indexes of refraction than the other fillers.

The extended titanium pigments consist of a combination of the TiO_2, titanium dioxide, and barium or calcium sulphate. The zinc sulphide pigments include commercial zinc sulphide, high zinc sulphide lithopone, lithopone, and titanated lithopone.

High strength pigments are particularly valuable in light weight sheets such as air mail and wherever maximum opacity and sheet strength are simultaneously required.

TABLE IV
Percent Brightness of Filler Grade Clays

	Airflated Clays	Water Washed Clays		English Clay
		Fine	Coarse	
G. E. Brightness	78-81	80-83	79-82	84-90

6. Precipitated Calcium Carbonate

Precipitated Calcium Carbonate, as compared to its counterpart ground chalk, is more desirable since it is made with a controlled particle size. Its amount in the beater is limited in that it hinders rosin sizing when used in large amounts. It is made by the introduction of scrubbed flue gases into a calcium hydrate solution. Another method is to mix solutions of soda ash and slaked lime. In alkaline pulp mills it is a by-product of the causticization of the soda salts.

Retention

By retention is meant the pounds of filler retained in the sheet per 100 pounds of filler added to the beater. The variables affecting retention are numerous and not too well understood. It is sufficient to say that accurate retention figures are gathered only by sustained runs of several days, preferably weeks, with every effort made to control these variables. In a large mill, for instance, it may be necessary to run a filler simultaneously on all machines so as to correct for any "broke" that might be transferred between machines.

Some of the factors affecting retention are:

1. *Degree of beating* or hydration of the stock. By fibrillating a stock to a greater degree, a larger surface area becomes available for the entrapment of filler. Here the amount of broke furnished to the beater may greatly affect the retention.

2. *Machine Operation.* Increased machine speed will usually decrease retention. However, the length of the wire, design of the machine inlet, shake, number of suction boxes and rolls, as well as the vacuum carried are important considerations.

3. *Basis Weight.* With increase in the basis weight, retention is improved. However, this becomes less apparent with extremely heavy weight grades.

4. *Beater Additives* such as alum, size, sodium silicate, starch, and sodium aluminate play an important part in aiding retention. However, no two mills will agree 100 percent on the effects of these materials.

5. *Particle size and shape* of the filler appears to affect retention. Recent evidence indicates that a proper distribution of particle size and shape results in a more closely packed medium which in turn greatly improves the retention behavior.

It has been theorized that filler is retained by:

1. *Filtration* or the separation of the filler from the water in the sheet caused by its inability to pass through the interstices between the fibers.

2. *Coflocculation* or the attachment of filler to fiber because of interfacial forces. The filler pigment builds up on other particles already flocculated to the fiber.

3. *Mechanical attachment* or the wedging of filler particles into imperfections on the fiber surface.

The best method of decreasing filler losses to the sewer, of course, is the proper operation of a closed white water system. The water from the machine pit, together with the repulped broke, is passed over a vacuum filter. The recovered fiber and filler then reenters the system through the fan pump or at some other suitable point.

Depending upon the type of filler used, the stock to which it is added, and the other factors of mill operation already mentioned, retention values in the various mills run from a low of 40 to a high of 85.

Conclusion

I have attempted to list some of the reasons why fillers are used and their characteristics. I have given a description of the mining, processing, and handling of clay, which is the predominant filler in use today. An intelligent approach to the problem of choosing the proper filler for any particular mill can be made only if there is cooperation between the technical man and the practical mill operator. Such an approach often leads to the manufacture of better paper at minimum cost — the aim of every paper producer in today's competitive market.

Paper Fillers

William R. Willets

B.S. New York State College of Forestry, 1926; 1926-1929, Research Chemist, Oxford Paper Co.; 1929-1923, Engineer, pulp insulation, Western Electric Co.; 1933 to date, Chief of Paper Deevlopment Laboratory, Titanium Pigment Corp.; 1942-1944, on loan as dollar-a-year man for War Production Board, Conservation Division, as consultant on Pulp and Paper, and Printing and Publishing.

General

The loading or filling of paper with finely powdered mineral materials has been common practice for many years and although in the earlier days it was considered as adulteration it is now well recognized that fillers make papers more suitable for many end uses. Virtually no paper for use in the graphic arts industry is today made without loading.

It is a well recognized fact that fillers improve the printing properties of paper by increasing its opacity, decreasing show-through, improving ink receptivity and giving more body and better formation to the sheet. Fillers improve the "feel" of paper and result in a better finish on calendering.

The older fillers were prepared by mechanical methods from natural minerals such as clay, talc, chalk and gypsum. Today many fillers are prepared by a combination of mechanical and chemical means from these naturally occurring minerals and in addition there are chemically precipitated materials such as calcium carbonate, calcium sulfite and blanc fixe. Within recent years the use of opaque pigments such as titanium dioxide, lithopone and zinc sulfide, prepared by involved chemical processes, has increased rapidly.

There are certain qualities to consider in selecting a filler. Naturally it should be free from grit and other extraneous matter and have good color brightness. Today most fillers commonly supplied to the paper industry to meet such requirements in greater or lesser degree but there are other properties worthy of consideration.

A filler with a high refractive index will have better opacifying power than a filler with low refractive index. Opacity is dependent on the difference in refractive indices of the components of the sheet—that is of the cellulose fiber, air and filler. If the sheet is waxed, the air, with a refractive index of 1.00, is replaced by the wax with a refractive index of 1.53 similiar to that of cellulose. Since the difference in refractive indices is thus reduced the sheet becomes more transparent, to an extent dependent on the refractive index fillers are effective in producing satisfactory opaque, white and bright waxed papers and boards. The same factors hold true when a sheet is printed because here the penetration of the printing ink vehicle renders that portion of the sheet beneath the printed character transparent, resulting in "show-through." If the air voids in a sheet of paper are reduced by long beating and hydration, or by high calendering, the opacity is also lowered. A good example of this is unfilled glassine whose opacity is developed by drastic hydration in the beater and hard calendering of the sheet. While the dry brightness of a filler is of importance in producing brightness in paper, the refractive index is also of importance and if this is high, the filler will have greater brightening effect because of its high tinting strength. It is logical that dull fillers will not aid in producing bright, ness, although they may aid opacity by the absorption of light.

Particle size is also of importance in producing opacity and brightness and the optimum is considered to be in the neighborhood of half the wave length of light, or about 0.3 microns. Small, uniform particle size also aids in producing a good finish. Fillers vary in their ability to aid in the production of high gloss or calendering.

Fillers should be chemically inert so as not to react with any of the other materials used in papermaking or subsequent converting and printing operations. It is almost impossible to size a sheet containing an alkaline filler (e. g. calcium carbonate) by the usual rosin-alum techniques. Chemically inert fillers vary in their effect on sizing although it has been reported that the effect is slight up to 10 to 15 percent filler content. The retention of soluble fillers (e. g. gypsum) is poor and fillers of high specific gravity (e. g. barium sulfate) are also apt to be poorly retained and furthermore tend to give a two-sided sheet.

In general, fillers tend to increase the weight of paper more than its bulk but the tendency varies with different fillers. The use of too much filler is apt to give a soft sheet and also result in dusting. Naturally, fillers decrease the strength of paper because they are used on a weight basis and thus actually replace the strength-giving component, that is the fibers.

The best filler to use for a given type of paper will not necessarily be the best for a different type. The cost of a filler is an important consideration from an economic viewpoint and frequently will play a large part in the selection. The selection of a filler should be made on the characteristics which will determine its ability to produce the type of paper required.

While the various fillers will be described in more detail in following sections, *Table I* summarizes some of the more important properties.

Low Refractive Index Fillers

This group of fillers all have refractive indices close to that of cellulose, namely 1.53. In this group will be found the greatest tonnage used by the paper industry.

Clay: Clay was probably the first filler used and still holds a predominant place with the annual consumption being in the neighborhood of close to half-a-million tons. Formerly much of the clay used in this country was imported from England but today the bulk of the filler clay is mined here, most of it in the southeastern states especially Georgia and the Carolina's. It has been estimated that the known sources of clay in the southeast are over 100 million tons. English clays are usually primary or residual clays, that is they are found at the point where they were formed by the weathering of weldspathic rocks; domestic clays are secondary or sedimentary clays in which the weathered rock is carried some distance by the erosion processes and deposited.

In mining clay, the overburden is stripped off by power shovels and the crude clay then removed to the clay

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2.

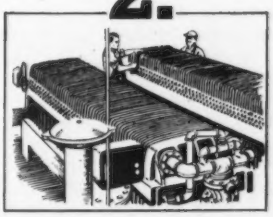

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TABLE I
Characteristics of Paper Fillers

	Appr. Comp.	Specific Gravity	Refractive Index	Average Particle Size Microns	Dry Brightness %
Barium Sulfate					
Barytes	$BaSO_4$	4.48	1.64	2-5	95
Blanc Fixe	$BaSO_4$	4.35	1.64	0.5-2.0	98
Calcium Carbonates					
Natural-ground	$CaCO_3$	2.7	1.56	3-5	93
Precipitated	$CaCO_3$	2.7-3.0	1.56	0.2-0.5	95
Dolomitic preciptated	$\{CaCO_3 \{MgO. \lfloor MgCO_3$	2.7-3.0	...	0.2-0.5	95
Calcium Sulfate					
Natural (Gypsum)	$CaSO_4$, $2H_2O$	2.36	1.52	....	..
Anhydride	$CaSO_4$	2.30	1.58	....	..
Calcium Sulfite	$CaSO_3$	2.51	1.57	6-7	92-96
Clay	Hyd. Al. silicate	2.5-2.8	1.56	0.5-1	70-90
Diatomaceous Earth	SiO_2	2.3	1.33	2-10	60-90
Talc	Hyd. Mg silicate	2.8	1.57	1-10	70-90
Titanium Pigments					
Anatase Titanium dioxide	TiO_2	3.9	2.55	0.3	98.5
Rutile Titanium dioxide	TiO_2	4.2	2.70	0.35	98.0
Titanium Calcium	$70CaSO_4$, 30 rutile	3.25	1.98	0.55	98.0
Zinc Pigments					
Lithopone	$28ZnS$, $72BaSO_4$	4.3	1.84	0.35	98
Double strength litho.	$50ZnS$, $50BaSO_4$	4.2	1.91	0.35	98
Titanated lithopone	82 lithopone, 18 TiO_2	4.2	1.91	0.35	98
Zinc Sulfide	ZnS	4.0	2.37	0.3	98
Zinc Oxide	ZnO	5.6	2.01	0.3	98

mill. Most filler clays are produced by the "air floating" process. The clay is first reduced by roll crushers or similar devices to small chunks about the size of an egg. These are fed continuously to a rotary drier and from there to various types of air-floating equipment. Generally the process comprises a pulverizing unit followed by equipment providing a controlled upward flowing current of air into which the finely ground clay particles are fed under such conditions that particles of the required fineness are transported by the air into suitable collecting chambers. Coarser lumps or oversize mineral impurities are either separately rejected or else fed back into the pulverizer and reduced to suitable particle fineness. Such air-floated clays always issued from the production stream in finely powdered form which in some cases may be too "dusty." Therefore, the powdered clay is occasionally subjected to conditioning treatments, such as flaking in which the fine clays are sprayed with water to produce small pellets, or by compression to remove some of the entrained air. Higher grade clays, such as are almost invariably used for coating and occasionally as fillers, are produced by the wet process. The crude clay is mixed with water, deflocculating agents added, and the suspension hydraulically classified by flowing it slowly through horizontal launders, by passing it through hydroseparators or similar devices or by treatment in continuous centrifugal processes. The slurry may then be decolorized by chemical bleaching processes. The suspension is flocculated and the clay particles allowed to settle, followed by filtration on filter presses or rotary filters. The filter cake is dried on rack cars in heated tunnels, in rotary driers or by extruding in the form of noodles which are deposited on continuous belts which are dried by passage of the belt through drying chambers. Occasionally the clay is deflocculated and made fluid and either shipped in tank cars in this form (at about 70 percent total solids), or after drying by pouring the fluid mass on heated metallic drums in which case the clay forms thin flakes or chips.

Clays, although essentially hydrated aluminum silicate, vary in such important characterstics as color, brightness, composition, particle size distribution and price depending on their sources and method of preparation. The clays used as fillers are usually of the air-floated type and have larger average particle size and a wider size distribution, as well as generally poorer color and brightness, than the wet process clays used for coating. The particle size and shape, which is believed to be platelet in form, probably determines the degree of finish that can be obtained with a clay filled sheet.

A photomicrograph of filler clay particles is shown in *Figure 1.* This and subsequent photomicrographs are shown through the kind permission of the Research Department, Titanium Division, National Lead Co.

Clays are shipped in bulk in box cars, or in bags, and occasionally as a high total solids slurry in tank cars. When purchased in bulk in box cars it is usually unloaded by air or suction into silos. When packed in bags, the bags are usually stacked on pallets for easy handling. It may be added dry to the beater but is frequently made up into a slurry, stored in agitated tanks and drawn off and screened as needed.

Clay is used in almost all types of printing papers and in the top liner of patent coated board. The amount will vary considerably with the different types of paper but will range from a

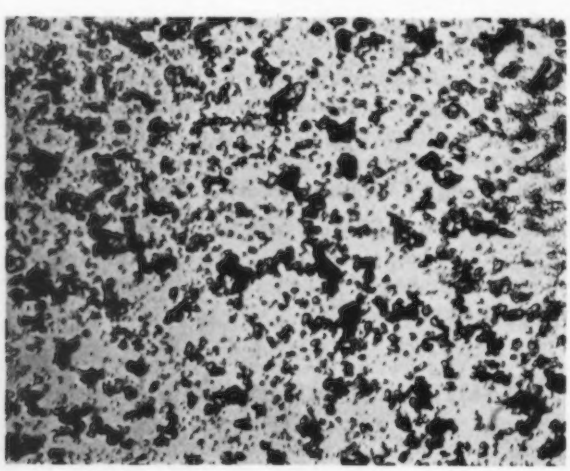

Figure 1. Filler Clay X600 dia. ⟷ 10 microns

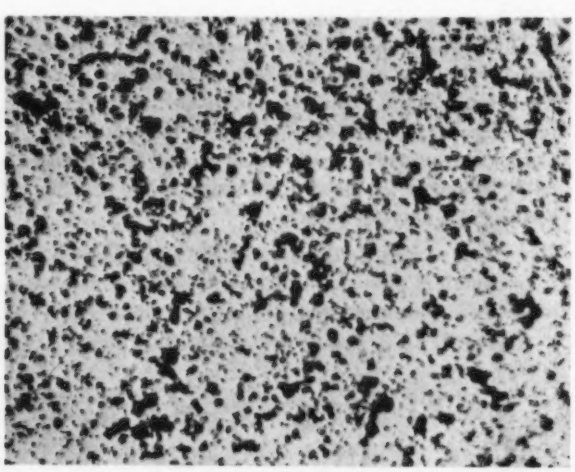

Figure 2. Precipitated calcium carbonate X600 dia. ⟷ 10 microns

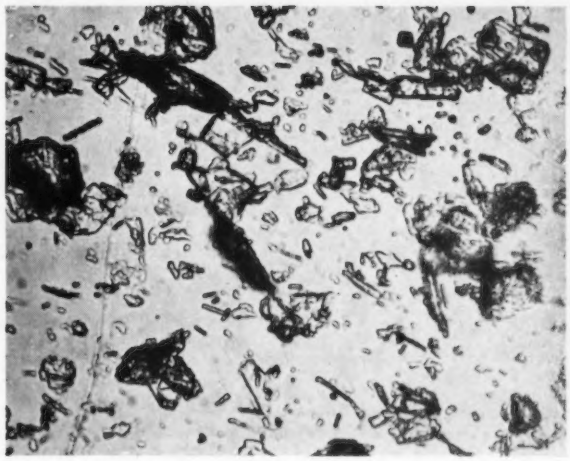

Figure 3. Talc X600 dia. ←→ 10 microns

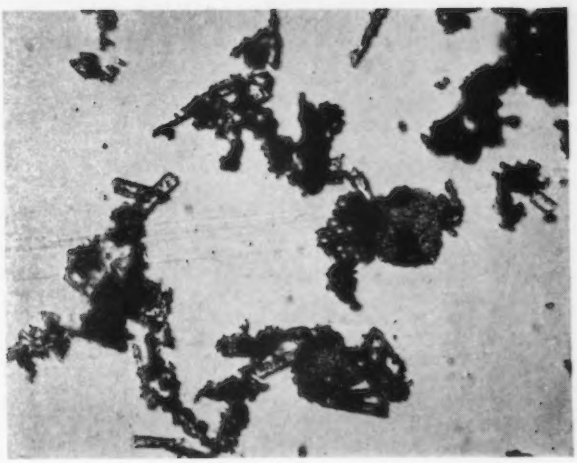

Figure 4. Diatomaceous earth—X600 dia. ←→ 10 microns

lower limit of approximately 5% to an upper limit of 20% or even more.

Carbonate Fillers: These fillers are second in importance tonnage-wise to clay. They are generally classified in two groups, the natural occurring mineral which is ground and separated by various air-floating and wet techniques (ground whitings) and the precipitated carbonates. Their chemical composition will vary with the composition of the lime used, from pure calcium carbonate to mixtures of varying composition of calsium carbonate, magnesium carbonate and magnesium hydroxide. Precipitated carbonates are made in a variety of ways. When alkaline pulp mills are adjacent to the paper mill the calsium carbonate mud recovered as a by-product in the causticization of the soda salts is further processed by settling and filtering to remove dissolved dirt. Another method is to pass cleaned furnace gases containing large amounts of carbon dioxide through solutions of calcium hydroxide (slaked lime) with the formation of calcium carbonate. Still another method is the treatment of soda ash solutions with slaked lime with the formation of caustic soda and calcium carbonate.

In any of these methods, the control of temperature, concentration, agitation and the like is important in governing the particle size distribution. After precipitation the calcium carbonate is filtered, washed, dried and pulverized for shipment in bulk or in bags. If the calcium carbonate is prepared as a by-product of pulp mill operation adjacent to a paper mill it is frequently used in slurry form without drying.

As noted above, the particle size distribution of the carbonate fillers will vary with their method of preparation, with different types available most suitable to the grade of paper being manufactured. Natural whitings are entirely calcite in crystalline form, while precipitated whitings may contain various amounts of aragonite. Calcite has a lower specific gravity than aragonite, 2.71 as against 2.95. There are many crystalline forms of calcite, but in general they fall into the rhombohedral class of the hexagonal system. Figure 2 shows a photomicrograph of precipitated calcium carbonate. The calcite crystal is birefringent or doubly refractive with the principal indices 1.658 and 1.486. In general, the carbonate fillers have better brightness and whiteness than clays or talcs. On a cost basis, they are in line with the clays being available at different prices depending on the type selected. The one serious handicap in the use of carbonate fillers is that the paper cannot be sized by the usual rosin-alum technique: When it is desired to color or tint stock containing carbonate fillers specially selected dyestuffs are necessary because of the alkaline reaction.

Carbonate fillers are used widely in magazine and bible papers, either alone or in combination with other fillers, with ash contents up to about 25%. They have high oil absorption and so are very receptive to printing inks. A special form of precipitated calcium carbonate is used in practically all cigarette paper since it gives not only improved brightness and color but also imparts certain porosity and other properties needed in such a sheet to produce proper burning qualities.

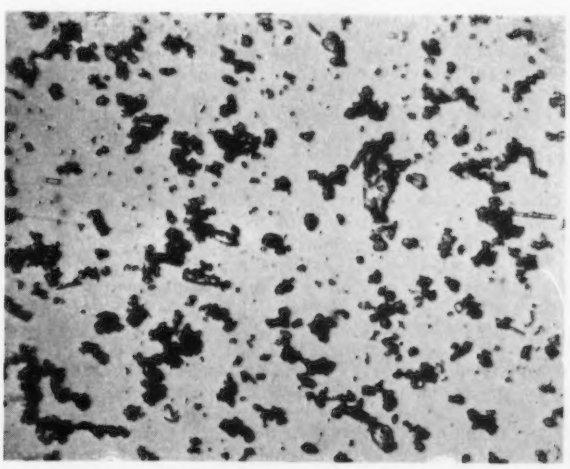

Figure 5. Calcium sulfate—X600 dia. ←→ 10 microns

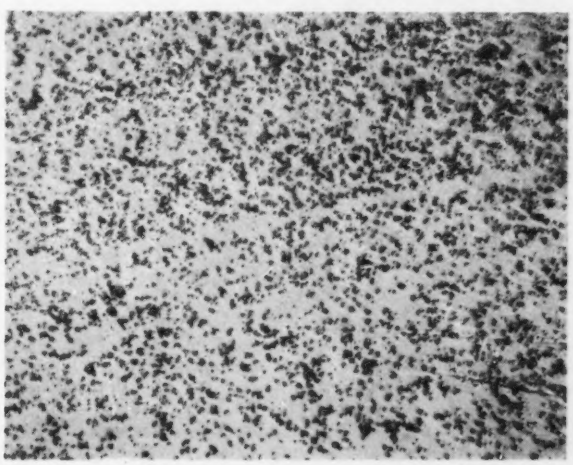

Figure 6. Blanc fixe—X600 dia. ←→ 10 microns

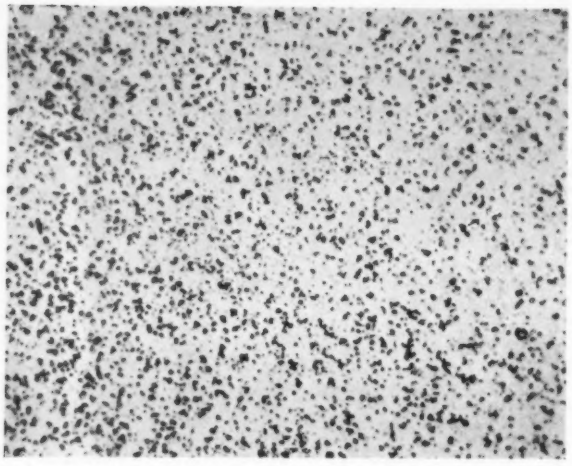

Figure 7. "Titanox" A—X1200 dia. ←→ 10 microns

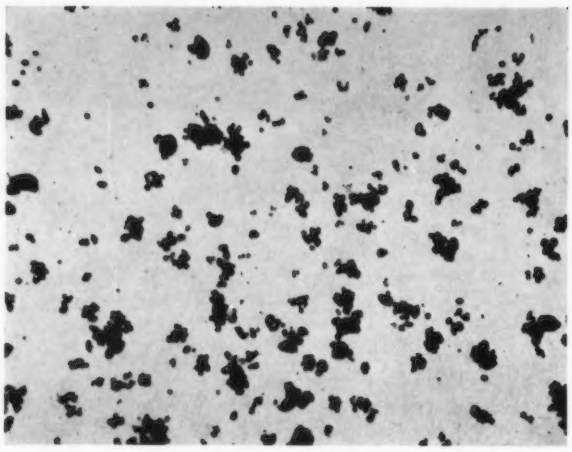

Figure 8. "Titanox" AMO—X10,000 dia. ←→ 1 micron

Talc: (Talc asbestine, agalite, soapstone) is a natural occuring mineral mined in northern New York, Vermont and California. Chemically, talc is largely a hydrous magnesium silicate but may occur as a double silicate with aluminum, the magnesium being largely in excess. It rarely occurs as well-formed crystals but usually as fibrous or foliated aggregates. A photomicrograph of talc is shown in *Figure 3.* Talc is a secondary mineral having as its origin either sedimentary or igneous rocks such as tremolite, serpentine or dolomite. Therefore talc as commonly produced often contains some of the original constituents of the rocks from which it was formed. Talcs from different localities vary widely in chemical composition.

Most talc is mined underground with the shaft usually sunk in an ore body corresponding to the dip of the vein. After removal of the crude talc it is refined by milling, grinding and air floatation. The grinding and refining of talc have been greatly improved in recent years so that the grades available have much less grit and other deletorious material than formrely.

Because of the fibrous or foliated nature of the talc aggregates, the particle size is larger than for clay. The mineral has a characteristic soapy feel and if used in large quantities is apt to impart a greasy feel to paper. The amount used is generally less than for clay or calcium carbonate, and rarely constitutes over 10 percent of the furnish.

The use of talc in the paper industry has declined in recent years although the consumption is still considerable, especially on the Pacific Coast where it is used in many places because of the proximity of the source to the mills, as compared with clay. It finds considerable application in the top liner of lined board, as it is said to aid drainage through the wire and to have good retention.

Diatomaceous Silica: This material (also known as diatomaceous earth, diatomite, kieselguhr and infusorial earth) is a comparative newcomer to the paper field. It is an amorphous silica formed from the residues of aquatic plants known as diatoms and natural occurring grades are composed almost entirely of the fossil remains of these diatoms. Properties of the natural material can be altered by processing (such as flux calcining) to produce products with modified characteristics. For example the natural material has a brightness of about 60 percent while a modified material with a brightness of 90 percent is available. The particle size varies widely, from 2 to 10 microns, and the shape is also variable as the fossil remains are fine, hollow, disk, needle and multi-shaped, and the forms largely remain in the commercial product. *Figure 4* shows a photomicrograph of diatomaceous earth. Because of its hollow nature, diatomaceous silica is very bulky.

Orginally, diatomaceous silica was used in small amounts as a pitch remover but more recently the use has been extended. The material has been said to improve the drainage rate on paperboard machines as well as to give better color and brightness. It has also been reported to improve the retention of high priced opaque pigments such as titanium dioxide.

Calcium Sulfate: This material is obtainable in a number of different forms. Gypsum is a natural calcium sulfate containing two molecules of water of crystallization. It may be used as such after careful grinding but is usually prepared by grinding, calcining, fine grinding, washing and quick drying to prevent rehydration. The original material loses about 21 percent of its weight on ignition while the calcined filler only loses 0.5 percent to 2 percent. Anhydrous calcium sulfate is known as anhydrite. There are also forms of artificially prepared hydrated calcium sulfates available. A photomicrograph is shown in *Figure 5.*

Since calcium sulfate is soluble in water (about 1 part to 400-500 parts of water) its retention is poor. There is also a tendency for the dissolved material to crystallize and fill up the felts on the machine. Calcium sulfate fillers (which are sold under a variety of trade names) are used in various types of writing papers for improvement of color.

Calcium Sulfite: This is one of the newer fillers and is produced by passing hot sulfur burner gas (17 percent to 18 percent sulfur dioxide) into a mechanically produced spray of milk of lime at 50° C. to 60° C. with the concentration 100 grams to 110 grams per liter calcium oxide.

Calcium sulfite is the normal lime salt of sulfurous acid with the chemical formula $CaSO_3 . \frac{1}{2}H_2O$. There is 7 percent of water of crystallization present but this water is not released below a temperature of 350°C. and therefore the moisture in the filler persists through the drying operations normally used in paper manufacture. The particles are flat, porous plates 1 to 3 microns in size. Strong acids react with calcium sulfite liberating sulfur dioxide but alkalies have no effect. The pH of a water suspension is between 8 and 9 but can be adjusted to between 5 and 9.

Calcium sulfite was originally developed as a substitute for clay in sized label and magazine papers and is extensively used by one company.

Barium Sulfate: Various forms of barium sulfate are occasionally used as paper fillers. These include ground barytes prepared by grading the natural ore according to color and then grinding in ball or tube mills with various means of separation until the desired degree of fineness is reached, and artificially prepared precipitated barium sulfates (blanc fixe) produced by various methods. A photomicrograph of blanc fixe is given in *Figure 6.*

The use of barium sulfate is very limited because its high specific gravity makes retention poor and also tends to give a two-sided sheet. Also the cost in comparison with other low-refractive index fillers is high. Occa-

sionally it is used where a heavy, dense sheet is needed or for printing papers that must lie very flat.

High Refractive Index Fillers

This group of fillers includes a number of opaque white pigments originally developed for the paint industry. Their opacifying and brightening power is several times that of the low refractive index fillers, and their cost is also in proportion. As discussed above, the fact that they tend to remain opaque when in contact with wax makes them exceedingly adaptable to making opaque waxed papers. They are also useful in producing other types of opaque food wrapping papers such as opaque glassine.

As a matter of fact, these synthetic pigments are used in every type of paper in which opacity, color and brightness are of importance. For reasons given above they reduce show-through and improve printability with overall better appearance and superior legibility. Their use makes possible the manufacture of lighter-weight book, magazine and catalog papers, without loss of opacity. They are widely used in opaque bonds, offset and ledger papers because the amount of filler required to produce the desired opacity is not sufficient to have any appreciable deleterious effect on strength. The same point explains their usage in drinking cup stock where a definite improvement in appearance is obtained without loss of other desirable properties. Small amounts used in the top liner of lined and patent coated boards improve brightness and color because the high opacity of the pigment greatly increases the covering power of the liner. The reasons for their use in waxing boards for butter cartons, frozen food packages and the like, are obvious. Large amounts are used in absorbent papers that are to be impregnated and laminated with synthetic resins.

Titanium Pigments: By far the most widely used opaque pigment is titanium dioxide. This is produced from ilmenite (an iron titanate) which is widely distributed throughout the surface of the earth. Two primary sources of supply at present for domestic pigment manufacture are the natural beach sands in India, and the massive rock deposits in the Adirondacks. The manufacture of titanium dioxide is a long, involved process and consists essentially of crushing and concentrating the ore, and milling to 200 mesh. This ground ore is reacted with concentrated sulfuric acid with the formation of iron and titanium sulfates which are brought into solution with water and dilute acid. The ferric iron is reduced to the ferrous state and the solution passed through a long series of settling and washing tanks to remove insoluble impurities following which the bulk of the iron is removed by fractional crystallization. The solution is then hydrolized by heating to precipitate the titanium as a complex hydrate. This precipitate is carefully filtered and washed and is finally calcined at very high temperatures in rotary kilns to produce titanium dioxide. Calcination is followed by various grinding procedures. The finished pigment is usually shipped in 50 pound bags.

There are three principal titanium pigments: The anatase crystalline form, the rutile crystalline form and a composite pigment consisting of 30 percent rutile and 70 percent calcium sulfate anhydrite. Titanium dioxide is chemically inert and will not react with any of the materials used in papermaking or subsequent converting or printing operations. The retention of titanium dioxide has been shown to be superior to that of clay. However, it should be noted that the calcium sulfate portion of the titanium calcium composite is soluble and therefore its retention, except in well closed white water systems, is apt to be low.

The anatase form of titanium dioxide is the most widely used. It has better color and is softer than the rutile form which however has somewhat greater opacifying power. Because of the greater hardness, slightly poorer color and higher price of the rutile form (which brings the economics of its use close to that of anatase), the rutile is generally used only in special absorbent types of paper for resin impregnation and lamination, where its particular properties are of importance. Photomicrographs of the anatase and rutile forms are shown in *Figures 7 and 9,* respectively. Electronmicrographs are shown in *Figures 8 and 10,* respectively.

A titanium dioxide content of 1 percent will produce the same opacity in a sheet of paper as 10 percent to 15 percent of a low refractive index filler such as clay, with the brightening effect in approximately the same ratio. In many types of paper the pigment is used in conjunction with clay or one of the other low refractive index fillers.

It is difficult to state the titanium dioxide content of various types of paper because it varies widely with basis weight and end use but, in general, groundwood catalog will contain up to 2 percent in conjunction with much higher amounts of clay; magazine papers may contain up to 3 percent or 4 percent with the balance of the ash (which may be as high as 20 percent or even more) clay, calcium carbonate or other low refractive index filler; book papers, especially those used for textbooks, schoolbooks and reference books of all kinds up to 5 percent on a total ash content of 10 percent to 15 percent; opaque offset 4 percent to 6 percent depending on the basis weight, with a total ash of around 10 percent; high grade bible as high as 15 percent; airmail up to 7 percent or 8 percent; opaque bonds from 3 percent to 6 percent; papeteries up to 5 percent; opaque waxing up to 5 percent; opaque glassine about 5 percent with semi-opaque about 2.5 percent; drinking cup stock 1 percent to 2 percent; lined and patent coated boards up to 3 percent or 4 percent in the top liner; waxing boards up to 4 percent; absorbent paper for resin im-

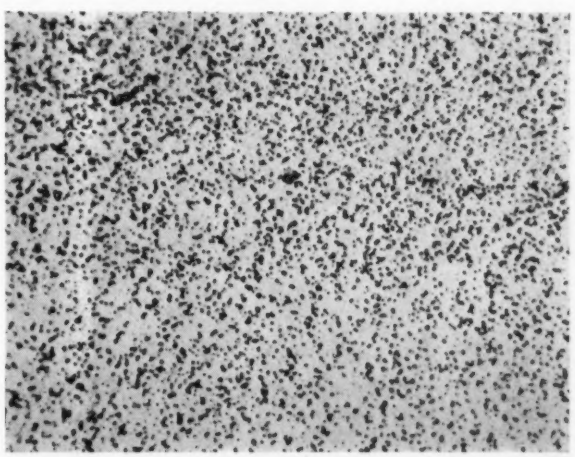

Figure 9. "Titanox" RA—X1200 dia. ←→ 10 microns

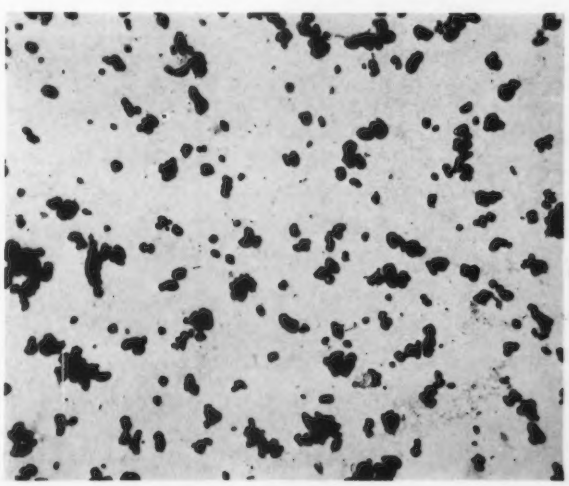

Figure 10. "Titanox" RA—X10,000 dia. ←→ 1 micron

pregnation and laminating 15 percent to 20 percent; and with varying amounts being used in many other grades such as fancy wrapping tissues, cover papers, and vulcanizing fiber, to mention a few.

Zinc Pigments: These opaque pigments are made in a variety of types but the opaque constituent in all of them is zinc sulfide. This pigment is prepared by passing hydrogen sulfide into a solution of a soluble zinc salt. The resulting precipitate goes through a number of subsequent operations including filtering, washing, drying, calcining, quenching, drying, disintegration and packaging. About twice as much zinc sulfide as of anatase titanium dioxide is required to produce equivalent opacity and brightening effects. A photomicrograph is shown in *Figure 11* and an electronmicrograph is shown in *Figure 12.*

Normal lithopone, which consists of 28 percent to 30 percent zinc sulfide with the balance essentially barium sulfate is produced by a cross precipitation of solutions of barium sulfide and zinc sulfate, with subsequent treatment of the precipitate very much as for zinc sulfide. The opacifying power is less than half of that of zinc sulfide. There are also available double strength lithopones, containing 50 percent zinc sulfide, and titanated lithopones made by blending about 85 percent normal lithopone and 15 titanium dioxide.

While the consumption of these pigments is much less than that of titanium dioxide they all have been used as paper fillers. Zinc sulfide is widely used in absorbent papers in amounts up to 25 percent for subsequent impregnation and lamination with urea and melamine resins.

There are several reasons why zinc sulfide pigments have not met with as wide use at titanium pigments. Costwise, based on opacifying and brightening power, the zinc pigments are actually more expensive, although in some cases cheaper on a pound basis. Titanium dioxide is chemically inert, while zinc sulfide is reactive under acid conditions. Therefore unless the amount of alum is carefully controlled so as to maintain a reasonably high pH (above about 4.8 or 5) there is danger of a reaction with the copper in the alloys used in the machine wire and elsewhere with the production of copper compounds which will have a marked darkening effect on the paper.

Loading and Retention

Formerly fillers were added dry to the beater and this is still common practice in many mills. Other mills prepare water slurries of the filler for ease of handling, and screen the slurries into the beater to remove lumps and extraneous matter. While common practice is to add the filler to the beater, or elsewhere during stock preparation, some mills add slurries to a stock chest or meter them in at the fan pump. Various methods have also been developed for adding fillers at some point on the fourdrinier wire. The object of many of these later innovations has been to increase the retention of the filler by reducing sewer losses.

While there have been several formulae developed for calculating retention the term is defined most simply as the ratio of the amount of filler in the finished sheet to that present in the beater furnish, usually expressed as a percentage. The problem of retention has been receiving increasing attention because it is not only uneconomical to lose any filler (or fiber, for that matter) to the sewer but also because such losses become much more significant with high priced fillers, and also because of the growing necessity for reducing stream pollution.

Therefore most mills have installed equipment to minimize sewer-losses. There are many types of white water and save-all systems, the primary object of all being the reduction of sewer losses, but a description of them is beyond the scope of this article. They involve various types of save-alls, filters, settling or flotation tanks and the like, with the prime purpose to return the white water solids to the furnish and the clarified waters to the beaters, for dilution in other parts of the process, and to the showers. In general, a white water recovery system is tailor-made to a particular mill or even to a specific paper machine in a mill.

In addition to the recovery system, which is probably the most important factor in reducing shrinkage, there are many factors which affect retention. It is rather obvious that a soluble filler will be more poorly retained than an insoluble filler in view of the large quantities of water involved in paper manufacture. A filler with high specific gravity will be more poorly retained than a lighter weight filler and will also tend to give a more two-sided sheet. High machine speeds with concurrent rapid drainage and the use of high suction will also tend to lower retention. Hydration resulting from beating increases retention because the interstices between the fibers are reduced and their surface area increased by fibrillation. All other things being equal a heavy sheet will retain more filler than a light-weight sheet. The use of the proper amount of alum at the optimum pH has been found to be of prime importance.

Filler particles are retained in the paper web by the combined action of several factors. The simplest of these is "filtration," that is the filler is held in the web because the particles are larger than the spaces between the fibers. Since both fiber and filler carry negative colloidal charges there will be no colloidal attraction and in this simplest case the retention will be governed by the weight of the web, the size of the inter-fiber interstices and the degree of suction. This explains why increased hydration with decreased size of the interstices, and increased sheet weight, both give increased retention.

The colloidal and chemical factors affecting retention can be largely ex-

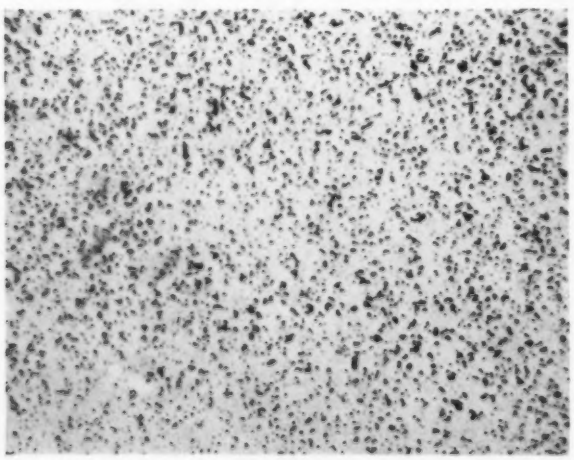

Figure 11. Zinc sulfide—X1200 dia. ←→ 10 microns

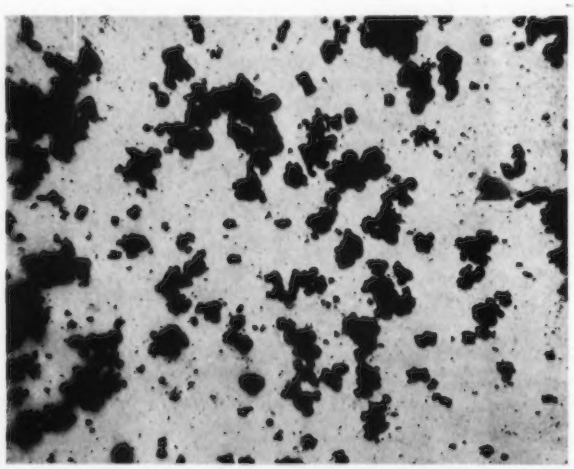

Figure 12. Zinc sulfide—X10,000 dia. ←→ 1 micron

plained on the behavior of alum at the proper pH. Alum has a marked effect in increasing retention not only because of its flocculating action but probably more because under the correct conditions alum hydrolises to form positively charged alumina which acts as an electrostatic cement binding the negatively charged filler to the negatively charged fiber. The optimum alum and pH conditions to produce the maximum retention probably vary from mill to mill, but experimentally it has been shown that about 2.5 to 3 percent alum at a pH of 5 to 5.5 gives maximum retention.

Filler Testing

A number of tests can be made on fillers as received at the papermill, but any detailed discussion of these would be beyond the scope of this article. Such methods are given in detail in the literature, especially that of the Technical Association of the Pulp and Paper Industry and the American Society for Testing Materials.

Moisture is readily determined by drying at 100-105° C. unless the filler is of such a nature as to lose chemically combined water at that temperature. The chemical analysis of fillers, both as received and after they occur in the paper follow along general qualitative chemical analysis methods.

The determination of over-size particles and grit can be made by sieving water slurries on suitable wire sieves, for example a 325 mesh sieve will retain particles greater than 44 microns. The determination of true particle size, especially in the submicroscopic range, is much more difficult and it is doubtful whether most mills would have the time or equipment to obtain particle size distribution data. There are many methods for doing this: settling or ultracentrifuge sedimentation techniques, gas adsorption methods and the use of the electron microscope which gives valuable information not only on particle size distribution but also on particle shape as well.

The color, brightness and opacifying power of a filler are chiefly of interest in relation to the effect they will have on such properties in the finished sheet, and such effect will be dependent on the refractive index of the filler as well as on its dry color and brightness. Therefore the best way to evaluate such properties is to incorporate the filler in a sheet of paper at varying contents and determine the results obtained, but this is a fairly lengthy and involved process for routine control. In checking a shipment against a standard, the two may be pressed side by side on a black surface and the appearance compared, with small differences in brightness and color being evident. If it is desired to compare the two in the wet state they are reduced to putty-like consistency with water and pressed side by side between glass plates and examined. More refined techniques are available for the determination of color and brightness involving considerable equipment. The filler must be reduced to the desired degree of fineness by the removal of all lumps and pinheads. It should then be dried since the amount of moisture (especially with clays) will affect the color and brightness. The filler is compacted by various means. One of these consists of placing a sample holder made of a 3 to 4 inch section cut from a 1½ inch brass pipe upright on a smooth piece of plate glass placed on a bathroom scale platform. The powdered filler is poured into this upright tube to about a third of its depth and a plunger forced down on it until the scale reads 50 pounds. Variations in pressure (in the case of clays) may result in differences of 3 points in brightness. The sample in its holder is a convenient entity for measurement on optical instruments, such as a brightness tester or a spectrophotometer.

The Perfect Filler

The best filler for one type and grade of paper might not be the best grade for another, and fillers should be selected on the basis of the characteristics most suitable for the paper under consideration and its end use. However, were it possible to produce the perfect filler, its properties and characteristics could be postulated as given below:

(1) It would have a reflectance of 100 percent in all wave lengths of light so that it would have maximum brightness and whiteness.

(2) It should have a very high refractive index, so that it would have maximum opacifying powers.

(3) It should be completely free from grit or extraneous matter and have a particle size distribution close to 0.3 microns diameter, approximately half the wave length of light.

(4) It should have a low specific gravity and be soft and non-abrasive.

(5) It should be capable of imparting to paper a surface capable of taking any desired finish from matte to the highest gloss.

(6) It should be completely chemically inert and insoluble.

(7) It should be completely retained in the paper web so that there would be no sewer losses.

(8) It should be reasonable in price.

Obviously such a "perfect filler" is not available. The cheap fillers with their low refractive indices are not very good opacifying and brightening agents, although they do vary in these respects. The opaque pigments are excellent opacifying and brightening agents but are expensive. At any rate, the above check list furnishes a means of considering which filler to select for the particular job in hand.

PULPS for every PAPER MAKING REQUIREMENT

KORSNAS AKTIEBOLAG
BLEACHED SULPHITES
Roburwite
Korsnas Tissue
Korsnas Super Tissue
RAYON PULPS
Dissolving & High Alpha Pulps for Rayon, Plastics & Specialties
BLEACHED SULPHATES
"Vigorwite"—Extra White Bleached Kraft
"Manila Kraft"—Extra Strong Semi Bleached Kraft
SPECIAL SULPHATE
"Herculite"—Special Bleachable Strong

MO & DOMSJO A. B.
BLEACHED SULPHITES
White Horse Strong
White Horse Greaseproof
Special Bleached Birch
White Aspen
Special Purified Aspen
RAYON PULPS
Dissolving & High Alpha Pulps for Rayon, Plastics & Specialties
BLEACHED SULPHATES
Husum Extra White Bleached Kraft
Husum White Birch
Husum Bleached High Alpha

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UNBLEACHED SULPHITES
Storvik "HS" Extra Strong
Mitscherlich

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ESTABLISHED 1916

Starch Sizing of Paper

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Introduction

My assignment is to present to you a discussion on the sizing of paper with starch products. Before proceeding to this specific subject, I believe it is appropriate to spend a few minutes discussing properties of starch, how starch is made, and the different types of modified starch used for sizing paper. My experience in the paper industry has indicated that many people that use starch do not understand some of the fundamental properties of starch, particularly its physical and colloidal characteristics.

Starch is the chief reserve carbohydrate of all plants. It is one of the most widely distributed substances in the vegetable kingdom occurring in seeds, in the vegetative parts of plants, such as tubers, in the living cells of the pith, and in the cortex of roots and stems. It is found in the latex of certain plants and it may be found in transitory form in green leaves. It is found in large quantities in those plants where it is stored as a permanent reserve. This is especially true of some seeds or grains which may contain as high as 70 percent starch. In tubers, roots and pithy stems it occurs in concentrations up to 30 percent.

In the plant, starch occurs as a biological entity usually referred to as a granule. These granules are formed and laid down in the plant during the formation of reserve carbohydrates. Starch granules from different sources show much variety in shape, size, and other physical characteristics. Microscopic examination of the granules along with staining with iodine allows the starch chemist to identify most varieties of starch. *Figures 1 and 2* show some of the fundamental differences in the appearance of different varieties of starch.

Figure 2 shows the characteristic appearance of the starch granule when viewed under the microscope in polarized light. This anisotropic characteristic of the starch granule is not fully explained. It is interesting to note that the typical cross pattern completely disappears when the starch is suspended in water and heated to the gelatinization point.

Figure 3 shows the behavior of the starch granule as it is heated in water. As the temperature increases the granule begins to swell, water is imbibed, and the total volume of the granule increases immensely. This reaction takes place at varying temperatures, depending upon the specific variety of starch being investigated. With corn starch, which is shown in these illustrations, the gelatinization occurs at approximately 170 degrees Fahrenheit. Previous to attaining this gelatinization temperature the starch granules behave as small spheres suspended in water. However, as soon as they become gelatinized a colloidal suspension is formed which has a viscosity far beyond that expected from the solids concentration. As heating continues and the temperature is increased this swelling continues for a period of time. As the boiling point is reached a maximum viscosity is obtained and the viscosity then begins to drop off rapidly. This viscosity drop is caused by rupture of the swollen granules which no longer function as swollen spheres suspended in water. However, the resulting so-called starch solutions are never true solutions, but are always at least partially colloidal suspensions. This behavior of starch during swelling indicates that if at any point we want the starch granule as large as possible for mechanical retention, then we should heat a starch solution to that point where the granules reach their maximum size with a minimum amount of rupture. For example, in a beater starch, or in a starch which is added to the pulp previous to casting the sheet, the granule will probably give best results by swelling to a maximum size before addition to the pulp. This should give better retention and more thorough distribution throughout the sheet. It also eliminates the necessity of being dependent upon gelatinization by the heat in the drying sections.

Chemistry of Starch

In the older literature it has been generally accepted that starch granules were incased in an outer sheath of cellulose-like material. The work of the past few years refutes this view and explains the resistance of starch granules to swelling as due to forces produced by the orderly arrangement of starch crystallites within the starch granule.

Recent work demonstrates that starch consists of two basic types of molecules which can be separated by fractionation procedures. One component, amylose, is selectively precipitated from an aqueous solution by the addition of certain alcohols. The unprecipitated fraction is amylopectin. These fractions can be purified by various procedures to give relatively pure fractions, the amylose actually crystallizing as needle-like crystals which tend to form starlike clusters or rectangular platelets. Fundamental studies of the structure of these components show that amylose is basically a long, straight chain molecule, while amylopectin has side chains at regular intervals. The branched structure of amylopectin retards crystallization of this fraction.

The fractionation of starch into relatively pure fractions has resulted in marked advances in the chemistry of starches in the past fifteen years. X-ray diffraction studies of the crystals of amylose as well as studies of oriented fibers and films has allowed the physical chemist to develop a fairly satisfactory picture of the unit cell in amylose. Basic concepts of the unit cell have been further developed by studies of the optical properties of amylose-iodine complexes. Under certain conditions, the structure of amylose is best interpreted as consisting of hollow helical tubes of indefinite length packed tightly together in pseudo-hexagonal fashion. The hollow helical tubes are formed by the long un-

branched chain of gluco-pyranose units, rotating around the central axis. Each rotation of the helix contains six anhydroglucose units.

Unfortunately, starch is not simply a mixture of the two molecular entities. The most recent fractionation studies have positively demonstrated that both amylose and amylopectin, although homogeneous with regard to type of molecule, are heterogeneous with regard to molecular size and other molecular properties.

Of practical importance is the demonstration that amylose is primarily responsible for the ability of starch to form gels in aqueous solutions. Relatively dilute (3 percent) solutions of amylose set to rigid gels, while high concentrations of amylopectin will not gel. The two varieties of corn starch demonstrate this property without fractionation. Ordinary corn starch contains 27 to 29 percent of the amylose fraction. A 10 percent solution of corn starch will set to a solid gel when cooled. On the other hand, waxy maize, which is pure amylopectin, will flow readily under the same condition.

Commercial Starches

Numerous starches are available on and industrial basis. However, the major starches used by the paper industry are corn, tapioca, and potato. Other starches which are available in the United States are wheat, sago, arrowroot, rice, barley, waxy-sorghum, waxy-corn, and sweet potato starch. Because I am most familiar with corn starch and its various derivatives and modifications, I would like to confine my remarks to corn starch. However, most of the statements made relative to corn starch will also be applicable to other commercial starches.

Four basic types of corn starch are available for application, the first three being commonly used in the paper industry. These are (1) common or unmodified starch, (2) oxidized or chlorinated starch, (3) dextrin and (4) acid modified starch.

(1) *Common or unmodified starch* is basically the same starch that occurs in the corn kernel, except that it has been separated from extraneous materials by chemical and mechanical methods. Such starch is available in either powdered or pearl form. Since it has not been modified in any way, it is the cheapest starch available. Because common starch is a very heavy bodied starch, it can be used only at low concentrations. It is modified for most sizing operations.

(2) *Oxidized or chlorinated starches* are prepared from common starch by treatment in an aqueous suspension with an alkaline solution of sodium hypochlorite. In this reaction the granule is not destroyed but the starch pastes prepared from the treated starches have a lower viscosity. In addition, the pastes are clearer, gelatinize at lower temperatures, give smoother, more adhesive pastes, and have less tendency to gel when cooled. Films formed by drying oxidized pastes are of a tough and horny character in comparison with the extremely brittle films of unoxidized starch. These properties make oxidized starch particularly adaptable to the surface sizing of paper.

The chemistry of oxidation is still very much of a mystery to the starch chemist. It is known that commercial oxidations introduce some carboxyl groups. There is also indication that some aldehyde and ketone groups may be formed. The carboxyl groups formed are neutralized with the excess caustic present in the oxidation so that the finished oxidized starches are actually sodium salts of carboxylic acids. The extent of oxidation, as measured by the number of carboxyl groups present in the commercially oxidized starches, is relatively small.

I would like to strongly emphasize that there is no evidence of substitu-

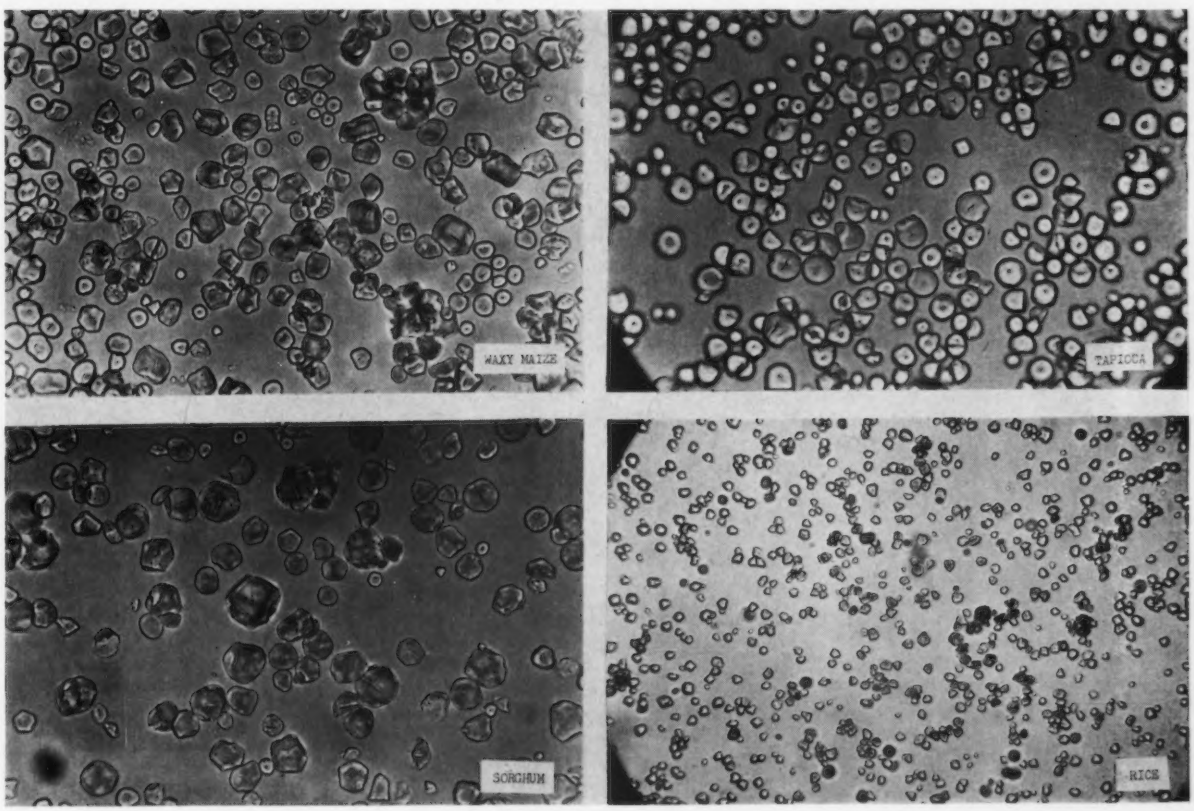


Figure 1—Granules of Waxy Maize, Tapioca, Sorghum and Rice Starch

tion of chlorine into the molecule. The term *chlorinated starch* indicates that there is a substitution of chlorine into the starch molecule. Since this does not occur, I believe that the term *oxidized starch* more adequately describes this type of starch product. Furthermore, non-chlorine oxidizing agents can be used in place of sodium hypochlorite. The term *oxidized starch* is being used more widely throughout the paper industry to describe this particulare type of starch.

Because these products are modified by chemical processes, because there are sizeable losses of organic matter during the operation, and because the capacity of filtering and drying equipment is markedly reduced when these starches are being manufactured, all oxidized starches command a premium price. The lowest oxidized starches sell for $.75 per 100 pounds over common starch, and the price varies with the degree of oxidation until the highly oxidized gums are prepared. These gums sells for a premium of $1.75 over common starch.

(3) *Dextrins* are prepared from unmodified starch by a dry roasting operation. Low moisture starch is acidified with very small quantities of concentrated hydrochloric acid or other acids. The low moisture acidified starch is then heated in a dextrin roaster to obtain the desired degree of modification. Variables that can be controlled are the moisture content of the original starch, the amountof acid used as the catalyst, the rate of heating in the roaster, maximum temperature reached, and the time of the conversion. By controlling these five variables, dextrins with varying water solubility, viscosity, color, and adhesive properties can be prepared. British gums are prepared by roasting without an acid catalyst. In special cases, stannous chloride, aluminum chloride, organic acids, alkaline compounds and many other can be used as catalysts. The dextrins generally used by the paper industry are relative low converted white dextrins. Dextrins are characterized by their low viscosity, low set-back in the concentrations used, and by their high adhesive power.

(4) The fourth type of modified starch is usually referred to as *acid modified starch.* Very little acid modified starch is used in the paper industry. Such starches are prepared by suspending common starch in water, adding either hydrochloric or sulphuric acid as a catalyst and holding the starch in suspension at an elevated temperature for varying periods of time. The resulting products give hot pastes which have lower viscosity than common starches at the same concentration. Acid modified starches, when compared to an oxidized starch with the same viscosity at elevated temperature, give very heavy semi-solid pastes when allowed to cool, in contrast to the oxidized starches, which remain fluid and workable.

Starch in Paper Manufacturing

Paper is sized to increase its resistance to water, to increase its physical strength, and to improve its surface characteristics. Water resistance by sizing is obtained almost entirely by incorporation of rosin into the pulp previous to formation of the sheet. Since I am not qualified to discuss rosin sizing, I would like to limit all of my future remarks to sizing with starch products.

Two basic types of sizing are utilized in applying starch to the paper. The first of these is referred to as *beater sizing.* It involves the addition of the sizing material, usually in colloidal suspension, before the sheet is formed. Such sizes may be added at the beater, at the fan pump, or at the head box. The starch is thoroughly dispersed in the pulp and is embedded in the sheet when the sheet is formed. In the second type of sizing applications, the size

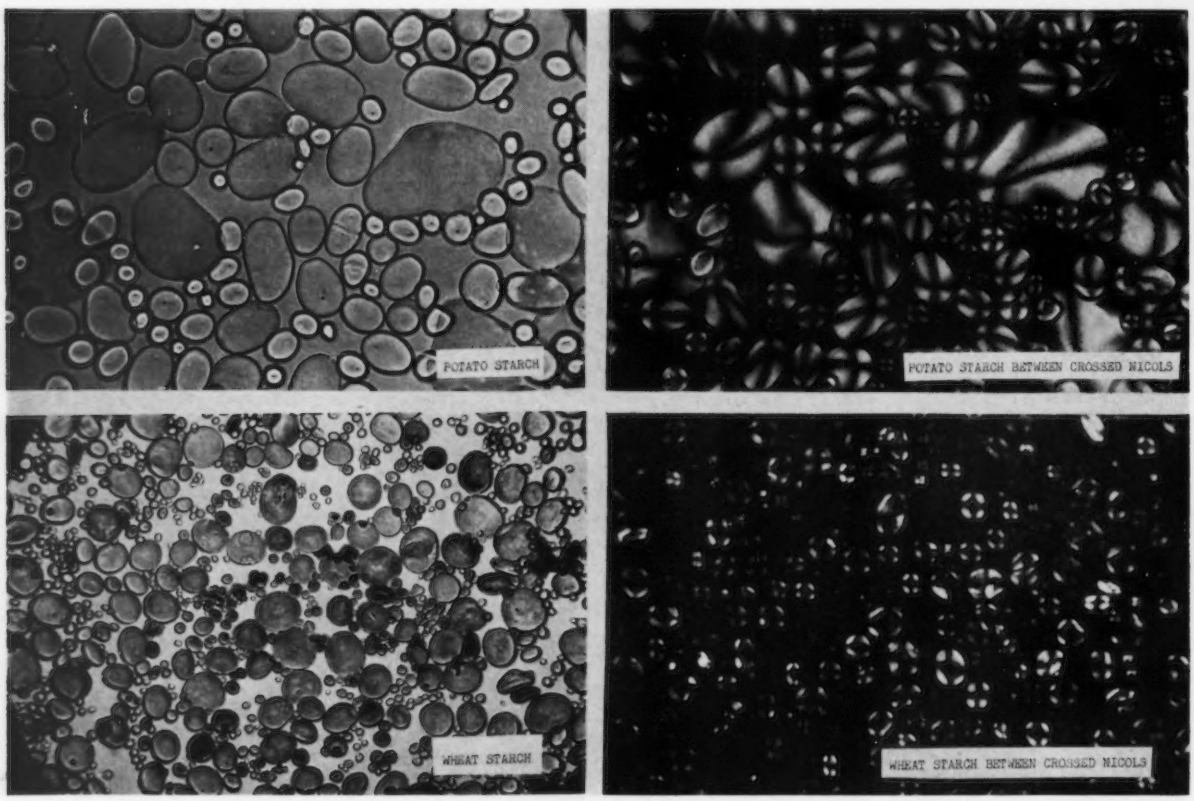


Figure 2—Potato and Wheat Starch Under Plane and Polarized Light

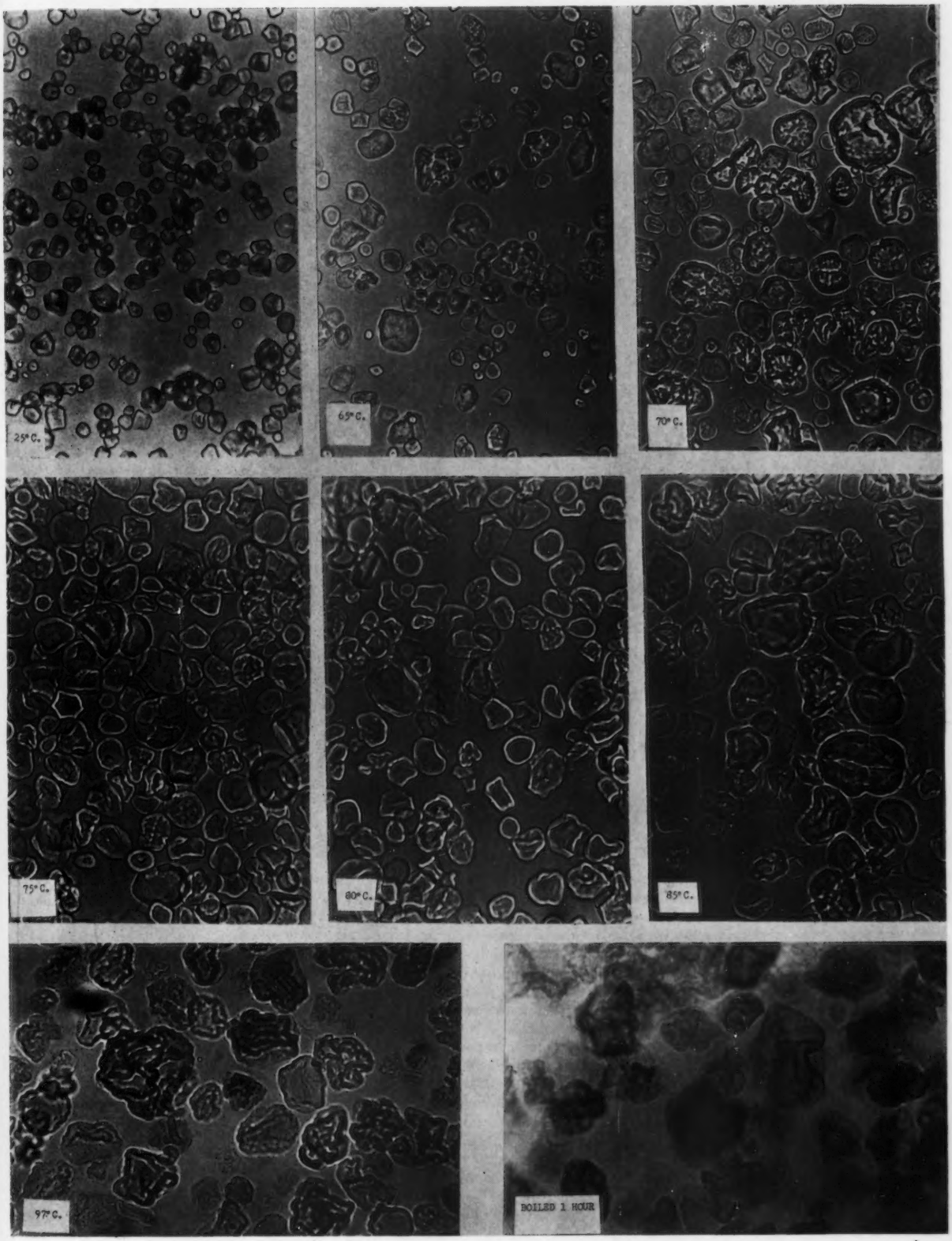


Figure 3—Corn Starch Granules Suspended in Water and Heated to Various Temperatures

is distributed on the surface of the sheet either before or after the sheet is dried, but definitely after the sheet has been formed on the paper machine. The second type is commonly referred to as *tub sizing.*

The purpose of sizing the sheet with starch products is to impart to the paper increased physical strength, to improve the surface characteristics and to make the sheet more resistant to such wearing actions as scuffing, and folding. Improvement in the appearance, feel, and rattle of the finished paper is a particular function of all surface sizing operations.

Beater Sizing

Although starch has been added directly to the beater for years in many mills, the exact value of the addition of this uncooked starch is still very widely debated. In many mill operations it can definitely be shown that an improved strength is obtained when a raw starch is added directly to the beater. On the other hand, it is known that a very large proportion of the starch added to the beater is lost from the sheet and leaves the system in the white water. Experience indicates that raw starch has so little adsorption affinity for most types of paper fiber that only 25 to 30 percent of the starch normally added to the pulp in the beater is retained by the fiber. It is also argued that the heat and moisture available at the drying rolls are not sufficient to completely gelatinize the starch that does remain in the sheet. Since such a large part of the starch added is lost from the sheet or is not completely active because of incomplete gelatinization, the economics of paper making do not favor the addition of raw starch at the beater.

If the starch is colloidally dispersed by gelatinization, the adsorbed starch paste will be spread over a greater area and will have a greater binding power. A greater proportion of the starch will also be retained. The concentration of cooking and the method of cooking vary from mill to mill. Concentrations of 3.0 to 8.0 percent are commonly used. Cooking procedure usually involves increasing the temperature of starch suspension to about 190 degrees Fahrenheit before addition to the beater. Because the gelatinized starch can be further broken down by action in the beater, the starch is often added at the end of the beating cycle to insure minimum break-down of the starch in the beater. The method of cooking the starch and the point of application is a matter of judgment and is dependent upon the type of raw starch used, the pH of the water, and the variations in the operations of the various beating and disintegrating equipment used.

The introduction of the cooking procedure is objected to by some mills. They have eliminated this procedure by buying pre-gelatinized potato, tapioca, or corn starch. These pre-gelatinized starches need only be dispersed in cold or slightly warm water in order to form satisfactory dispersions. Because of the additional processing which is performed at the starch processing plant, pre-gelatinized starches are premium priced products.

In order to obtain better gelatinization of the starch in the sheet when uncooked starch is added at the beater, some plants have used oxidized starches. These starches gelatinize at a lower temperature and therefore better gelatinization is obtained in the drying section of the paper machine. Some plants use oxidized starch for beater additives even when they have a cooking system. The desirability of using such modified starch is primarily a matter of economics and must be determined at the individual mill.

A modification of addition to the beater, which will accomplish the same purpose, is to continuously add cooked starch at the fan pump or the head box. This eliminates much of the disintegration which occurs by the action of the beater, the jordan, and other disintegrating equipment. Either common or oxidized starch can be used here. The starch is cooked in an aqueous dispersion at a concentration of 1.5 to 4.5 percent. The starch is then continuously added to the pulp at such a rate that from one to three percent of starch is added on the basis of the amount of pulp present. In addition to giving improvement in physical characteristics, many mills believe that the addition of the cooked starch under these conditions gives improved dispersion of the rosin, resulting in a more uniform rosin sizing operation.

Since the preparation of the original draft of this discussion an article by Wesley Pearl has appeared in the January, 1952 issue of TAPPI. The article is entitled, "The Sorption and Rate of Sorption of the Amylose Fraction of Starch by Papermaking Fibers." The last paragraphs of this paper can appropriately be quoted here.

> "Although the study of the role of starch and starch fractions in papermaking has only been started, some experimental results may have practical applications worthy of note.
>
> "Experimental evidence is now available to indicate that time is an important variable. Since the sorption of both fractions of starch increases with time, the farther back in the papermaking process that starch is added, the more time there will be available for sorption. The most logical point of application would be the beaters. Other investigations have shown, however, that starch added at the beater loses much of its effectiveness in improving strength properties if subject to much refining action. Therefore, a compromise should be made between sorption and possible deleterious effects of refining operations. The rate of sorption can be increased by increasing the amount of starch added.
>
> "Retention by sorption is greatly enhanced at low temperatures. If the starch can be added to the pulp in cold water before extreme dilution, a large amount of starch, especially the amylose fraction will be sorbed."

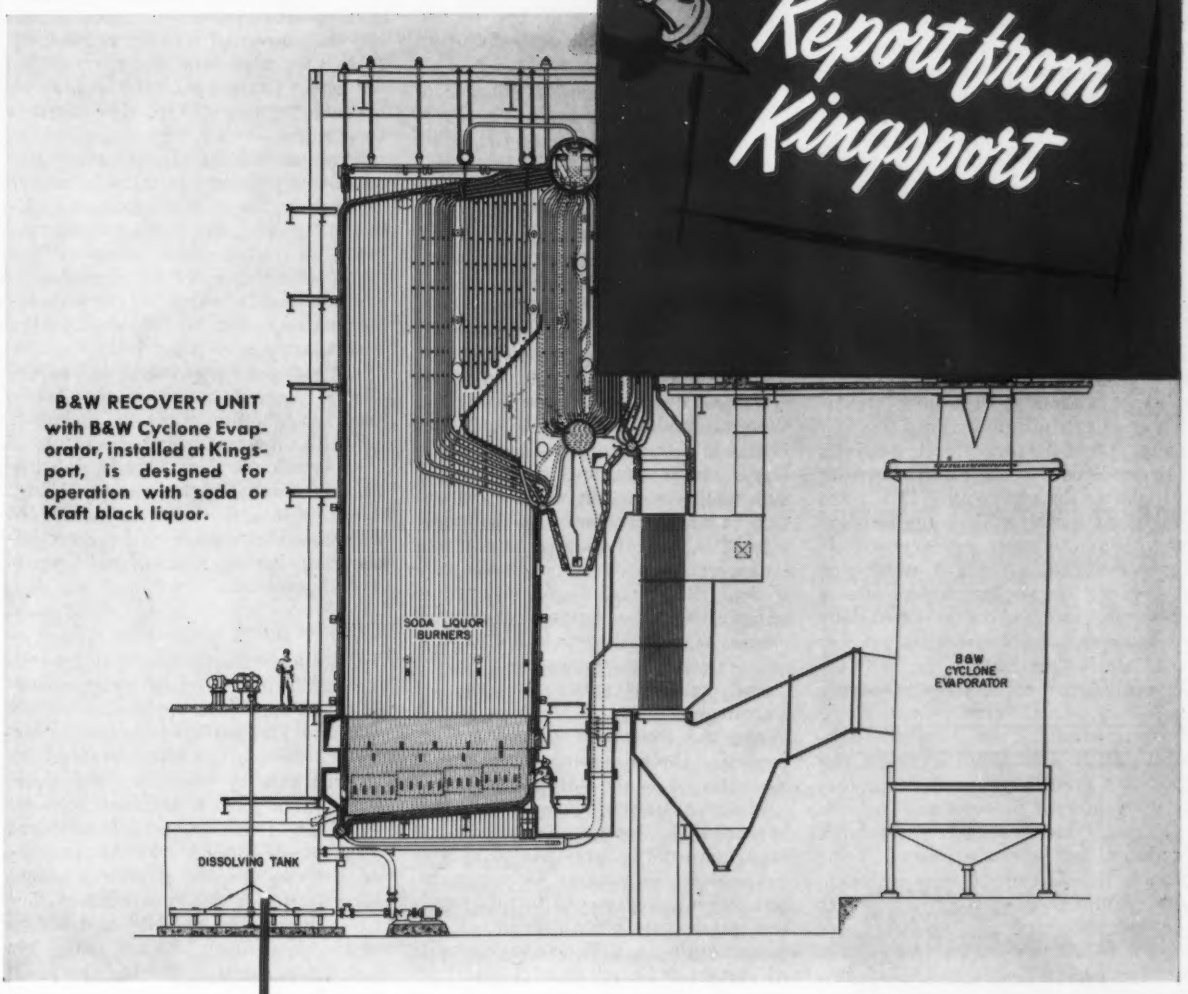
Tub Sizing

In tub sizing the preformed sheet of paper is immersed in a dilute size solution of low viscosity, the viscosity of the size controlling the degree of penetration into the sheet. Tub sizing is particularly important because it gives increased strength to the sheet, improves the surface characteristics, and also improves the appearance, feel, and rattle. All of these factors are extremely important in the merchandising and utilization of a sheet of paper. Unmodified corn starch has too high a viscosity to be a satisfactory product for tub sizing. It is thus necessary to decrease the viscosity of the starch by some conversion method.

Oxidized starches are widely used for tub sizing paper. The uniformity, stable viscosity, ease of handling, and other characteristics of the oxidized starch justifies their choice. The oxidized starch selected by any mill is dependent upon the particular operating conditions in that mill and the characteristics desired in the finish sheet. The intermediate and highly oxidized starches are commonly used at concentrations varying from .5 to 1.2 pounds per gallon, while the gum type starches are used at concentrations varying from .75 to 2.00 pounds per gallon. The oxidized starches are prepared by cooking at more than the desired concentration to approximately the boiling point. Usually they are held at this elevated temperature for from 10 to 30 minutes and then diluted with cold water to the desired concentration. The size solution is usually applied to the sheet in solutions maintained at 130 to 150 degrees Fahrenheit.

Dextrins have seen rather limited use in tub sizing. Some of the applications are relatively new and seem to be arousing a lot of interest. In these applications, dextrins are either used straight or in combination with

Report from Kingsport



B&W RECOVERY UNIT with B&W Cyclone Evaporator, installed at Kingsport, is designed for operation with soda or Kraft black liquor.

Designed to operate on a basis of 240 tons of pulp daily, and generate 107,000 lb. of steam per hr. at 900 psi and 750 F, a B&W Recovery Unit—since installation two years ago—has admirably fulfilled expectations in helping achieve better processing efficiencies and operating economies at the modernized Kingsport, Tennessee, mill of Mead Corporation. Largest recovery unit ever built for the soda pulping process, it was purchased to operate at approximately 60 per cent of its rated capacity, and under these difficult conditions has easily maintained desired heat and chemical recovery rates. The mill reports substantial savings in maintenance time and expense chargeable to recovery units. The new unit requires no hand lancing—automatic soot blowers do the job.

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oxidized starch to give specific properties to the sheets. Low soluble, white dextrins are used. These dextrins are usually prepared by suspending the dextrin in cold water, cooking to 190 degrees Fahrenheit and then applying at a concentration of six ounces per gallon. When using dextrins it is possible to go to higher solids than with either enzyme converted or with oxidized starches. The dextrins have the further advantage of being slightly less costly than gum starches. Their method of application and their behavior is comparable to that of the gum type oxidized starches. There may be a slight disadvantage in their higher water solubility.

Earlier in this discussion we mentioned that unmodified starch was usually too viscous to apply to a sheet of paper without modification. Oxidation and dextrinization reduce this viscosity and make dry starch products with modified viscosity characteristics available to the papermaker. The third method of modification is the common practice of the paper industry of buying unmodified starch and treating it at the mill by an enzyme conversion technique. Enzyme conversion usually produces an adequate size at a lower cost, but it does put on the mill the responsibility for controlling the conversion so as to give proper sizing characteristics. If an adequate technical staff is available to supervise this operation, then enzyme conversion may be the preferred procedure.

Enzymes are unorganized materials produced by microorganisms, being capable of effecting changes in indefinite quantities of substances on which they act, without being themselves used up or exhausted in any way. The enzymes which bring about the hydrolysis of starch are referred to as amylases or diastases. They are prepared from malt and bacteria, molds, or fungi. The exact mechanism by which enzymes attack starch is not known, but it is definitely established that the diastases act on starch in two ways. The enzymes liquify or dextrinize the starch, or they may saccharify the starch. In the liquifying-dextrinizing action, the enzyme apparently attacks the starch agglomerates in such a way as to produce a higher dispersibility, with some of the starch molecules being split into smaller molecules without the production of sugar. In saccharification, individual sugar molecules are split from the end of the starch molecule, resulting primarily in the production of dextrose and maltose. For preparing starch sizes for paper, enzymes must be selected which perform only the liquifying and dextrinizing action. Whenever sugar is produced, loss in sizing power results. The commercial enzyme generally chosen is referred to as alpha-amylase. If the correct enzyme is selected and properly applied, practically no sugars are produced, the adhesive and sizing properties of the treated starch being very similar to the original unmodified starch.

Enzyme conversion is dependent upon the kind of starch used, the enzyme selected, the size of the batch, the concentration of the starch, the type and performance of the equipment, the method of heating, the character of the water used, agitator speed, and other local conditions. This necessitates the establishment of a procedure and a control method for each mill. Conversion procedures are usually worked out with the enzyme supplier so that the conditions applied give the best results, with the enzymes selected. When a standard procedure is adopted, it should be carefully followed at all times. It is standard procedure in many mills to put the enzyme conversion on automatic control so that cooking cycles, rate of heating, rate of agitation, etc., are all automatically controlled. Best results are always obtained when the enzyme conversion process is carefully supervised. Potato and tapioca starch usually require slightly smaller amounts of enzyme for conversion than does corn starch. When the conversion procedures are properly applied, comparable results are obtained in the finished products.

Manufacturers produce starches that are specially treated to make them more uniformly susceptible to enzyme conversion. Treatments including special refining processes to further purify the starch, careful adjustment of pH, proper buffering to insure maintenance of correct pH's, addition of metal sequestering agents to prevent metal inactivation of the enzyme, and other treatments have all played a role in making enzyme conversion of corn starch feasible on a commercial basis.

Enzyme conversion procedure varies from mill to mill, from enzyme to enzyme. However, a general procedure is to add the starch to water at room temperature and stir until the starch is uniformly suspended. The pH is adjusted to 6.8 to 7.2 and then the enzyme is added. The steam is turned on and a definite time - temperature schedule followed. The temperature is usually raised slowly and uniformly to approximately 170 degrees Fahrenheit for corn starch. The rate of temperature rise is so adjusted that this temperature is obtained in about 30 minutes. For higher solids concentrations, that is from 20 to 30 percent, the time is prolonged to as much as 50 minutes. The batch is then raised to about 190 degrees Fahrenheit and is usually held at this temperature for about 15 minutes. This temperature treatment inactivates the enzyme and also thoroughly disperses all starch particles. The batch is then cooled and diluted to the proper application concentration. Enzyme converted starches are usually applied at concentrations of 6 to 15 per cent. The temperature application is varied from 130 to 150 degrees Fahrenheit.

There is considerable variance in the concentration and the temperature of application, due to the degree of penetration desired, the speed of the machine, and many other factors. The major advantages for enzyme conversion are usually lower costs at a variable viscosity that can be fitted to the particular type of paper being treated. Disadvantages are increased supervision requirements, a more complicated installation, and the inherent difficulties in controlling viscosity.

In some operations, clay is added to the tub sizing starch mixture. Under these conditions the sheet is loaded with clay, the resulting sheet, after calendering, having some of the properties of a coated sheet.

Calender Sizing

Calender sizing is much like tub sizing in that the sheet of paper is subjected to a surface application of size solution. This surface treatment is performed on the wet calender stack of the machine by means of the water boxes. The major users of calender sizing are found in the field of board manufacturers who wish to improve the printing surface of their products, particularly for gloss ink printing. The size solution fills the hills and valleys of the sheet much like tub sizing, but to a greater extent, holding the printing ink up on the surface and giving a clear cut and dense printing impression. It is well to emphasize here that the surface of the sheet can be improved by this treatment but that a sheet with such defects as lumps, or very wild formation cannot be made into a product having perfect printing qualities. In other words, the basic condition of the board being sized has a pronounced effect on the results obtained by calender sizing. No one can make second or third quality paper into a first quality grade simply by calender sizing.

Calender size starch is cooked in the same way as tub size starch but the range of concentration is greater. A very low concentration in the neighborhood of 0.15 pounds per gallon is used for "laying the fuzz" and "slicking up" the finish. A very high concentration of 2.0 pounds per gallon is used for obtaining high gloss ink printing characteristics. Any intermediate

concentration is used depending entirely on the results desired and the machine conditions of the user. The temperature of application is also dependent upon mill conditions, but usually ranges from 110 to 130 degrees Fahrenheit.

The highly oxidized gum type starches are used for work of this nature because of their low viscosity characteristic when cooked and applied at high solids concentration. A very recent advance in this field is the use of low water soluble, white dextrins as the sizing medium. These dextrins can be cooked and applied at higher concentrations than the oxidized starches if so desired. However, the principal amount of calender sizing remains with the oxidized starches and only specialized cases have changed to the dextrins.

Calender sizes are lubricated with such materials as paraffin oil, wax, wax emulsions or like compounds. This enables the size solution to withstand the nip pressure and relatively rapid setting of the surface size without sticking to the calender rolls. A size which sticks in this manner gives poor surface film with the consequent reduction in printing quality. In extreme cases of such sticking, a wrapped calender roll may result with the consequent machine breaks, lost production time, or even possible damage to the calender rolls themselves. The amount of such lubrication is from 0.5 to 4 percent based on the weight of dry sizing material and is usually incorporated in the product by the manufacturer. However, some paper mills prefer to buy unlubricated starch and do their own lubrication.

Coated Paper

Since it is understood that the subject of coated paper is to be completely covered in a later lecture, remarks made at this time on this phase of the industry will be of a very limited nature.

Paper is coated for the purpose of improving its appearance and printing qualities. This is particularly true in the field of advertising where many of the "lay outs" are designed for prints of four or more colors. For work of this nature printing surfaces of the utmost quality, ink receptivity and operational speed are required.

Paper Coating colors are composed basically of pigment bonded together and to the base stock with an adhesive. This adhesive may be starch, resin, casein, or like materials depending on the requirements and preference of the user.

Starch is the cheapest and most adaptable adhesive material available to the coating industry at this time. True, it leaves something to be desired from the standpoint of water resistance when compared to casein or some of the resins, unless it is treated with one of the water proofing resins such as urea formaldehyde. However, when so treated it compares very favorably with both casein and the resin type adhesives both as to water resistance and price.

Starch, as the adhesive, is used at from 12 to 25 percent of the weight of the pigment in the finished coating color. The adhesive quality at these levels gives very adequate bonding of the pigment to the base stock. The paper coater wishes to work at as high a solids level as possible. Some are operating at 60 to 65 percent solids and would like to go higher if possible.

Consequently, for this work where viscosity of the finished coating color is of paramount importance it is desirable to use dextrins, low viscosity oxidized gums, or low viscosity enzyme converted common starch.

The oxidized starches are cooked with water to 190 degrees Fahrenheit and the resulting paste mixed with the previously slurried pigment and other ingredients to give a finished coating color with the correct viscosity and solids content. The common starch is enzyme converted, in a manner very similar to that used for tub sizing, to the desired viscosity and then combined with the pigment slurry in the same way as the oxidized starch. A relatively new method of preparation of the coating color is to slurry both the pigment and common starch together, add the enzyme to this slurry and then convert the starch in the presence of the pigment until the coating color has the desired viscosity. The pros and cons of this method are still being argued strongly in the coating industry. The major advantages seem to be in a saving of labor, time, and equipment installation. The major disadvantage lies in the fact that the conversion is much more difficult both to perform and to control when carried out in the presence of the pigment than when done in the customary manner. The control problem particularly leads to erratic viscosity of the coating color with all the resulting coating problems.

Summary

Starch is applied to paper to increase the internal strength of the sheet and to improve the surface characteristics. Because of its desirable characteristics and its low cost, starch is by far the most widely used sizing material used by the paper industry. This usage will probably be expanded in the future because the starch producers recognize many of the problems of the paper industry and are striving to develop improved products for paper applications.

Conclusion

You men will soon be accepting positions on the technical staffs of paper companies. If at any time you encounter problems relative to the use of starch, the Technical Service Departments of various members of our industry will be pleased to have you ask for assistance. We will not always have the answer immediately available, but we usually can find the answers in a reasonable period of time. By cooperation on such problems, our industries can make marked advances in the betterment of our products. Close cooperation between our industries in the past has always been mutually advantageous. I am sure that future cooperation will continue to be as valuable.

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PULP AND PAPER MILLS—PLANTS AND FACILITIES
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The Dyeing of Paper

H. A. Lips

Attended schools in Yonkers, N. Y. Graduated from the Department of Pulp and Paper at the New York State College of Forestry at Syracuse, N. Y. in 1937. Joined E. I. du Pont de Nemours & Co. July 1939. Placed in charge of the Paper Dye Laboratory December 1945. Transferred to the Wilmington Office of the du Pont Co. January 1, 1952 as Sales Manager of the Lakes, Paper and Leather Section.

Introduction

The manufacture of paper is a compromise among numerous chemical and mechanical variables. Some of the chemical variables are strength properties of the pulps, sizing, loading, brightness, chemical additives, and color. Some of the mechanical variables that are adjusted to balance the sheet properties are beating and refining, dirt removers, consistency control, the setting of the slice, suction boxes, suction couch roll, presses, dryers, and calenders. In order to manufacture a saleable sheet of paper all of these variables have to be blended, and compromised with another very important factor—cost.

The dyeing process is often one of the last variables as far as the mill men are concerned and is adjusted accordingly. In most cases the coloring has to fit in with the mill process and only in isolated cases are special compensations made in favor of the dyeing process. The shade desired will, of course, determine whether bleached or unbleached pulp is used. On the other hand, the shade and type of pulp, the loading, the sizing, the use of other chemical additives, and the mechanical adjustments will all affect the dyes, the shade, and the fastness properties of the finished paper.

There are actually hundreds of dyes that can be used to color paper. From a practical point of view, however, there are probably only 50 to 60 important dyes and color pigments which are used extensively in the dyeing of paper. Most mills carry an inventory of between ten and twenty different dyes depending upon the grades that they manufacture. Practically all paper is dyed to some extent. All white papers are tinted and many unbleached papers are shaded to help control shade. It is, therefore, important that all technical men in the mill have some knowledge of the dyeing process. If there is an excess or a slight deficiency of size it will not be immediately noticeable. A similar change in the color formula may materially change the shade and it will be very noticeable.

Dystuff Classes

Before we undertake to study the variables that affect the dyeing process, let us study the characteristics of some of the classes of dyes. Paper can be dyed by beater dyeing, calender coloring, and by various conversion proc. esses. Beater dyeing is used to describe the coloring of the pulp in the beater and is used loosely to describe all methods of dyeing pulp before it is made into a sheet of paper. Some of the newer mills do not have beaters any more. These mills, therefore, color the stock in the chest or continuous metering. Since most paper is dyed by coloring the pulp before the sheet is formed, we will place greater emphasis on beater coloring.

Pigments. The first class of colors that we will consider are pigments. There are natural and synthetic pigments. Pigments are retained in paper by alum. Alum aids in holding the pigment on the fiber. The bond is fairly weak until the sheet is dried so that when the dyed paper goes over the fourdrinier wire color is drawn away from the bottom of the sheet leaving it lighter than the top side. This is known as two-sidedness. All pigments produce very two-sided sheets. The two-sidedness is most noticeable on fast machines equipped with a suction couch.

Natural Colors. Natural colors were undoubtedly the first dyes which were used to dye paper. They have been largely replaced by synthetic dyes which are brighter and tinctorially stronger. There are both organic and inorganic natural colors. Today probably the only important natural organic color is Sap Brown. This is a colored material which is mined as one of the decomposition products of vegetation between peat and coal. It is very weak tinctorially. It has excellent light fastness and is cheap. Its presence will weaken a sheet considerably and therefore its use is limited.

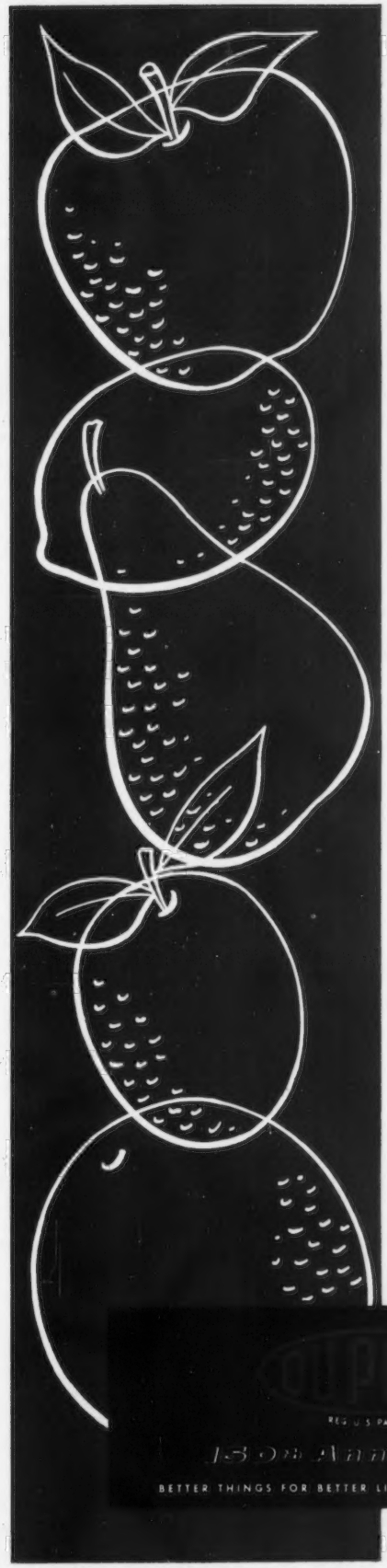
There are a few important natural inorganic colors. Actually clay, talc, and some of our other white pigments commonly used as filters could be considered natural inorganic colors. However, among the true inorganic colors the most important are the iron oxides. The red iron oxides are used extensively where light fastness is important. Iron oxides are quite weak and relatively dull in comparison with the synthetic dyes. They vary considerably in strength and shade but they are relatively cheap. They will tend to weaken the strength of the paper and therefore their chief use is in heavier weight sheets such as wallet paper. The yellower shades of iron oxide are sold as ochres and umber. They are even more limited in their use.

Synthetic Colors. Inorganic Pigments. Inorganic pigments are water insoluble colors which generally have good light fastness. They are used extensively in the dyeing of paper. They are usually used together with synthetic organic pigments and with organic, water soluble dyes. A typical example of an inorganic pigment is Chrome Yellow. This color is made by reacting sodium bichromate with lead acetate to form lead chromate. There are various shades of Chrome Yellow from greenish shades of yellow to a reddish, almost orange, shade. The redder shades are generally stronger and faster to light. These colors are sold as powders or pastes and are added as such to the beater. Another closely related pigment is Molybdate Orange. This color produces a bright orange with excellent light fastness.

Another inorganic pigment which is important is Prussian Blue, also known as Iron Blue or Soluble Blue. This color is tinctorially very strong and produces a bright, greenish shade of blue. It has excellent light fastness but is readily destroyed by mild alkali. It is chemically ferric ferrocyanide.

Ultramarine was at one time an important paper color. Today it has been replaced with synthetic organic dyes to a large extent. This color is extremely bright and has excellent light fastness even in light shades. It is tinctorially very weak and is sensitive to acids. It will lose strength if it stands for a long period of time in the beater in the presence of alum. It is used chiefly for tinting high grade rag content papers.

Carbon Black is also an important pigment. It is permanent to light and is cheap. It is relatively weak tinctorially and will smudge. It also has the disadvantage that it will weaken the sheet.



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Du Pont Dyes

There are other synthetic inorganic pigments which are used only occasionally. Among these are the Chrome Oxide Greens and the Cadmium Yellows.

Synthetic Colors. Organic Pigments. The use of synthetic organic pigments to color paper has increased considerably in the last decade. The demand for better light fastness for twisting paper used in automobile seat covers and paper rugs has been responsible for this trend. Synthetic organic pigments vary considerably in properties. In general they have much better fastness than the soluble dyes. There are many groups within this class and we will cover only some of the more important ones.

Phosphotungstic and phosphomolybdic acid toners of basic dyes is one of the most important groups and it would be well for all students of paper making to become familiar with this class. These types are sold under trade names such as "Halopont," "Solar" and "Helmerco." The most important shades are blues, violets, and a pink. These pigments are very bright and have fair to good light fastness. They are used primarily to tint white paper. In this use they serve the same function as bluing does in the laundry; to give a blue white shade which will appear visually brighter than the normal yellow white of bleached chemical pulp. These pigments are sold as dry powders which are readily dispersible in water and the suspension will, for all practical purpose, appear as a true solution. These colors are the chief tinting colors for white paper and are used in quantities from 2 to 6 ounces per 1000 pound beater or bleached chemical pulp.

Azo pigments is the class of synthetic organic pigments which is the most diversified and complex class. The chief use of this type of pigment is in printing inks. A few of these pigments are used in the coloring of paper. "Lithosol" or "Hansa" yellows compete with the Chrome Yellows. "Lithosol" Red CSP Paste is a bright, fast to light, red pigment. There are also other reds such as the Toluidine Reds, Para Reds, etc. which are used occasionally. These colors are also used extensively in coatings.

Naphthanil pigments are used for beater dyeing paper and at times in coatings. They are sold as water dispersible pastes and can be made into powder types. They are generally faster to light than azo pigments but are limited by their cost.

The *Phthalocyanine* blue and green pigments are among the most brilliant and fastest to light colors known. They are fairly expensive and are used primarily because of their excellent fastness properties and brilliance. These colors are permanent to light even in light tints. They are sold under trade names such as "Monastral" and "Heliogen."

Vat pigments are used to dye cotton and other textiles to give shades that are fast to light and to washing. They are dyed on textiles by temporarily solubilizing the water insoluble pigment with caustic soda and sodium hydrosulfite. In this form it dyes the fiber. The insoluble color is them reformed on the fiber and the color becomes an integral part of the fiber. Paper can be dyed in a similar manner, but this process is rarely used because it is complicated and more expensive than other methods of coloring. Vat colors are actually pigments and can be used as pigments to dye paper. They have excellent light fastness and are used where fastness is of prime importance. Selected vat blues are used as tinting agents for rag content papers. Other vat colors are used occasionally where the fastness requirements warrant. These colors are sold under numerous trade names such as "Ponsol," "Calcoloid," and "Indanthrene."

Soluble Dyes. The first synthetic soluble dye was Mauve discovered in 1856 by Sir William Henry Perkin. This was the forerunner of our present-day dye industry. The majority of the dyes used by the paper industry are synthetic soluble dyes. There are literally hundreds of dyes to choose from and one of the chief problems of the paper colorist is to select the correct dyes to met the requirements of the paper. Let us consider the characteristics of the various classes of Soluble Dyes.

The three main classes of soluble dyes are acid, basic, and direct dyes. These dyes are made water soluble by attaching a solubilizing group onto the color molecule. It is essentially the formation of a color salt. Let us consider common salt as a basis of illustrating the difference between acid and basic dyes. We could consider sodium chloride as the sodium salt of hydrochloric acid. The *sodium salt of a color acid* is an acid dye or a direct dye. They are usually the sodium salts of the dye sulfonic acid.

Basic dyes on the other hand are equivalent to the *dye hydrochloride.* Other acids, of course, can be substituted for the hydrochloride and we have sulfates as well as oxalates. The following three formulas illustrate these generalizations which we have just discussed:

1. Na Cl
   Salt
   Sodium Chloride
2. Na-Dye-Sulfonic Acid
   Acid and Direct Dyes
3. Dye-Hydrochloride
   Basic Dyes

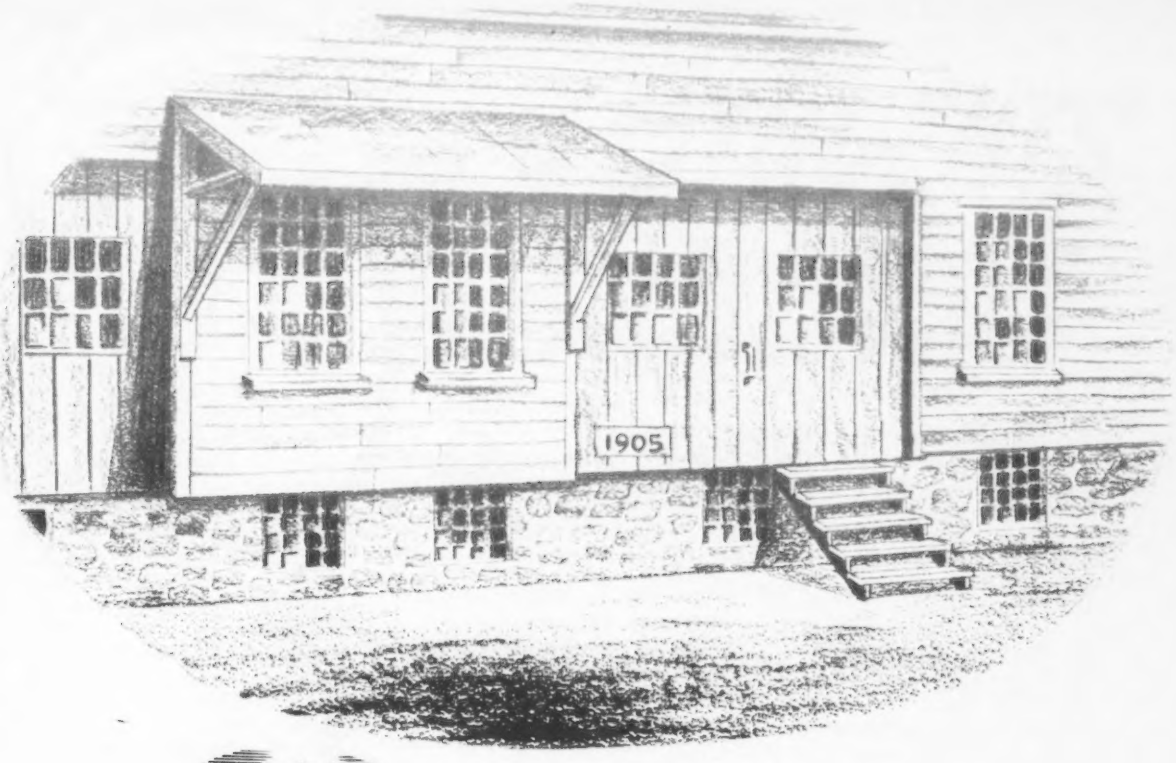
The chief difference between acid and direct dyes is not in the chemical formula but rather in regard to their affinity for cellulose. The name "Direct Dye" is used to classify those soluble dyes which are sodium salts of dye sulfonic acids which have a *direct affinity* for cellulose. Naturally there are some borderline cases where it is difficult to differentiate between acid and direct dyes. Most dye classifications, such as this differentiation, relate to the dyeing of textiles rather than paper.

It is possible, however, to establish a similar classification on paper. Acid dyes require size and alum to exhaust the dye on the fiber. It is impossible to dye unsized water leaf papers efficiently with acid dyes. Direct dyes, on the other hand, will dye the pulp without size or alum although the retention of these dyes is improved by the addition of alum or size and alum. Let us consider each class separately.

Basic Dyes. The first synthetic dye discovered, Mauve, was a basic dye. In a short time many other basic dyes were discovered. Basic dyes as a class are the strongest and the brightest dyes. They have the disadvantage that they are very fugitive to light. They are used extensively in the dyeing of paper for reasons of economy.

Basic dyes have relatively no affinity for cellulose and in most cases will not dye a highly bleached pulp without the assistance of a mordant. In order to dye cotton with basic dyes the cotton is first treated with tannic acid and then with tartar emetic. This known as tannin mordanted cotton. Basic dyes have a strong affinity for tannin mordanted cotton. The lignins and other impurities present in groundwood and in unbleached pulps have a similar attraction for basic dyes. Basic dyes will, therefore, dye unbleached pulps without size and alum. Basic dyes should not be used to dye bleached pulp except as topping agents where they are used in small quantities. Auramine and Rhodamine are retained somewhat better on bleached pulps than the other basic dyes. It is possible to dye basic dyes on bleached pulps with a mordant such as tannic acid and tartar emetic or a synthetic mordant such as Tamol P.

Since basic dyes have a strong affinity for the impurities in unbleached pulps and relatively no affinity for bleached pulps they must be used with caution on mixed furnishes. On a furnish of 10 percent unbleached sulfite and 90 percent bleached sulfite basic dyes would preferentially dye the unbleached fibers and leave the bleached fibers undyed. This would result in a mottled dyeing and clearly illustrates the necessity of care when using basic dyes on mixed furnishes.



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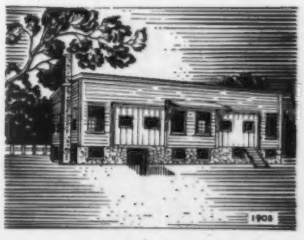

JOHN W. BOLTON AND SONS, INC., Lawrence, Mass.

Basic dyes are used extensively in dyeing unbleached pulps for reasons of economy. They are exceptionally tinctorially strong and are extremely brilliant. Their chief use is in beater dyeing paper but they can also be used for calender coloring and in aniline staining. In addition to being water soluble, these dyes are also alcohol soluble. Methylene Blue and Safranine have the poorest alcohol solubility. This is one way which can be used in identifying basic dyes in a sheet of colored paper. If the color bleeds in hot alcohol the paper was dyed at least in part with basic dyes.

The most important basic dyes are as follows:

Yellow—Auramine
Orange—Chrysoidine
Brown—Basic Brown also known as Bismark Brown
Red — Rhodamine, Safranine, and Fuchsine
Violet—Methyl Violet, Crystal Violet, and Ethyl Violet
Blue—Methylene Blue and the Victoria Blues
Green—Victoria Green also known as Malachite Green

Acid Dyes. Acid dyes as we have already mentioned have relatively no affinity for cellulose, nor do they have an affinity for the impurities in unbleached pulps. This property means that they will not granite or mottle in a mixed furnish. They require size and alum to aid retention and cannot be used for blotting and other grades of absorbent papers. Acid dyes are used to dye wool.

In general, acid dyes are not as brilliant nor as strong as basic dyes and are more expensive to use. There are many exceptions, as in every generalization that can be made. The acid oranges, Orange II Conc. and Orange RO, are used to produce brilliant shades of orange which cannot be matched either for shade and brilliance or for cost with combinations of basic dyes. Again Crocein Scarlet produces a scarlet shade of red the brilliance of which is difficult to match with basic dyes.

Acid dyes are much faster to light than basic dyes. Brilliant Crocein FL Extra Conc. is an outstanding example. This color has exceptional light fastness. Some of the acid dyes, however, have only moderate light fastness. Since acid dyes have no affinity for the fiber and are retained only by the mordanting action of the size and alum, they are not firmly bound. In deep shades, the backwaters coming through the wire will be highly colored. In most cases the color will bleed from the paper if the paper becomes wet. This eliminates these colors as candidates for coloring vegetable wrappers which will become wet. Also, the lack of affinity for the fiber will at times result in the color migrating due to the heat of the driers. This problem is particularly important in board mills where the driers are run very hot. The color "burns" toward the surface and at times the center of the sheet will appear essentially colorless.

Acid dyes are the most soluble class of dyes. This is, of course, one of the differences between acid and direct dyes and has a direct bearing on affinity. Some acid dyes such as Tartrazine and Naphthol Green are so soluble that they cannot be retained in the beater. These types are often used for surface coloring and dipping.

Some of the important acid dyes
Yellows—Metanil Yellow—Primarily for calender staining.
Quinoline Yellow — For Canary shades of bond and cover paper.
Oranges—Orange II Conc., Orange RO—Beater dyeing and calender coloring.
Reds—Crocein FL—This is the fastest to light soluble dye used for dyeing paper. It is non-two-sided.
Crocein Scarlet — Used primarily for dipping and calender staining.
Blues—Anthraquinone Blues — Used for blue and green bond and cover paper shades.
Green—Green BL and NV types—Beater dyeing, dipping and calender staining.
Blacks—Nigrosine Blue Black SX.

Direct Dyes. Direct dyes, as has already been mentioned, differ from acid dyes in their affinity for cellulose. They are less soluble than acid dyes. In beater dyeing, the backwaters are not as heavily colored as when acid dyes are used. Direct dyes, despite their affinity for the fiber, are retained better by the addition of salt and size and alum. In dyeing cotton with direct dyes, salt is added to the dye bath and the bath is heated. At the high temperature and in the presence of salt, the dyeing takes place rapidly with the color leaving the dye bath and exhausting onto the fiber. In beater dyeing heavy shades this same principle is followed. The beater is heated as soon as it is furnished. The color is then added and followed with 5 to 10 percent common salt. Most direct dyes are retained fairly well under these conditions. This is the procedure used to dye blotting and other absorbent papers.

The retention of direct dyes is improved still further by the addition of alum or, better still, with size and alum. Naturally, most grades of paper are sized and direct dyes color the sheet readily and exhaust well. When light and medium depth shades are dyed it is unnecessary to use either heat or salt. If over approximately ten pounds of direct dye is used per 1000 pound beater, it is advisable to use salt and heat the beater to improve retention.

Most direct dyes dye best at a pH of 4.5 to 5.5. This is the average pH range obtained using 2 percent size and 2½ percent alum. Some direct dyes such as Congo Red, Purpurine 4B, and Orange R are sensitive to acids and turn blue and dull at such a low pH. These colors are used for dyeing paper because they are economical. In this case a compromise must be made in favor of the dye for cost considerations. These particular colors are therefore dyed at a pH between 6.0 and 7.0 by the use of soda ash and sodium aluminate. Alum is essential for retaining size and plays a major role in color retention. For this reason it is essential to maintain the alumina percentage. The pH could be raised by simply reducing the amount of alum, but this would reduce the sizing and the color retention. Therefore, soda ash and/or sodium aluminate are used to raise the pH without reducing the amount of alum in the formula.

Some of the more important direct dyes used by the paper industry are as follows:

Yellow—Brilliant Paper Yellow — a bright, cheap, fast to light dye which is essentially non-two-sided. It is sensitive to alkali and will turn to a brilliant scarlet when spotted with 1 percent caustic soda.
Stilbene Yellow G Conc.
Yellow S3G, SXG, SXP, SXP Conc.
Yellow CH Conc.—Fast to alkali and ink eradicator.
Yellow NNL, BBL—Fast to light alkali and ink eradicator.
Orange—Orange R Conc. (Dye at a pH of 6.0)
Orange WS Conc. 175 percent
Brown—Brown N3G, D3GN
Red—Purpurine 4B Conc. (Dye at a pH of 6.0)
Red 8BLX
Fast Scarlet 4BS Conc. 150 percent and 4BA.
Blue—Sky Blue 6BX Conc. 150 percent
Deep Blue BH Conc.
Turquoise 8GLD Conc. 150 percent—A solubilized "Monastral" type.
Green—Green BXN Conc. 150 percent
Black—Blue E Double

Variables Influencing Dyeing

We have now studied a few of the

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general properties of the various classes of dyes which are used to dye paper. We will now cover some of the variables which influence the dyeing of paper.

The Pulp Furnish. The shade of the pulp will have a pronounced influence on the shade of the paper. Pulps themselves vary considerably in shade and in dye receptivity. This is particularly true of unbleached pulps such as kraft. It is impossible to match a shade which is lighter in shade than the base pulp using ordinary soluble dyes. All soluble dyes and many pigments are essentially transparent. It is impossible to raise the brightness by the use of soluble dyes. Under some conditions it is possible to improve the apparent brightness of the pulp. One example is the use of a tinting blue for tinting a white sheet. The blue makes the white appear brighter. Another example is the use of Auramine to improve the visual brightness of unbleached kraft.

Some pulps require more color to match a given shade than do others. Groundwood pulp and soda pulp require appreciable more color to match a given shade than would be required to match this shade using sulfite or kraft. Deinked stock and broke also vary in their fiber composition but also contain fillers and sizing agents which may effect pH.

Fillers. Fillers are being used in increasing quantities. As the price of pulp increases the trend toward larger use of cheap fillers such as clay, chalk, and talc will be extended. Clay is the cheapest filler and is therefore used to the greatest extent. Many sheets are being made with 10 percent clay.

Some colors have a preferred affinity for the clay in preference to the fiber and others a preferred affinity for the fiber. When a filled sheet is run over the paper machine the fillers are sucked away from the bottom side leaving a higher percentage of filler on the top surface. This is more pronounced on a high speed machine than it is on a slow speed machine because of the action of the suction boxes and the suction couch roll. If the color preferentially dyes the clay, the top side will be dyed deeper. This is true when Stilbene Yellow is used to dye a filled sheet. The opposite is true if the filled sheet is dyed with Brilliant Paper Yellow. This color has essentially no affinity for clay and preferentially dyes the fiber. In order to dye a filled sheet so that it is non-two-sided it is usually necessary to use a dye which will color the fiber together with a dye which will color the clay.

In the mill, a color that has affinity for the fiber in preference to the clay is known as a "bottom" color. Dyes with greater affinity for the clay are "top" colors. The balance will often work somewhat differently in each mill. All colored pigments are "top" colors. The pigment is actually mechanically held by the alum or the size and the alum. When the sheet which is dyed with a colored pigment goes over the wire the color is sucked away from the bottom side leaving this side of the sheet lighter in shade.

Fillers generally require increased amounts of dye. This is particularly true of opaque pigments such as TiO_2, titanium dioxide. The addition of 4 percent TiO_2 to the furnish will double the color requirements to obtain the same depth of shade. It will also alter the shade and tend to turn all shades toward a pink cast.

Sizing. Sizing, as has already been discussed, exerts a pronounced affect on color retention. Acid dyes cannot be retained without size and alum. In dyeing deep shades with acid colors, it is often desirable to double the quantities of both size and alum to increase the amount of aluminum ion without lowering the pH to the extent necessary if alum were used alone. This can be done by adding 1 percent sodium aluminate or sodium phosphoaluminate. These agents are alkaline and will raise the pH. This effect can be counterbalanced with alum to obtain the desired pH and aluminum ion required for efficient color retention.

Starch is often used in the beater to add certain sizing properties to the sheet. Some dyes have a strong affinity for the starch. If the starch is completely soluble this is of no importance. If, however, the starch is only highly swollen the dyed starch will show up as colored shiners in the sheet.

Influence of pH. The pH has a pronounced influence on the retention of dyes and sizing. Optimum sizing is usually also the point of optimum color retention. For most colors this is between 4.5 and 5.5. In a few cases, as mentioned under direct dyes, it is desirable to raise the pH to 6.0 to 7.0 by using soda ash and sodium aluminate.

Most dyes are brighter and faster to light at a high pH than at a low pH. Alum generally dulls the shade and reduces the light fastness; therefore, excessive quantities should be avoided unless necessary.

Order of addition. Order of addition is one of the common causes of trouble in a paper mill. Most of the complaints which are received relating to poor color control are a result of variations in the order of addition. This is particularly true of direct dyes.

Direct dyes are sodium salts and are generally more soluble under neutral or alkaline conditions than they are under acid conditions. It is therefore desirable to add these dyes before the size and alum or after the size but before the alum. The important point is to add the color before the alum. This procedure should be established in every paper mill as standard procedure and all mills should adhere to this procedure. This is particularly important with direct dyes but should be followed also with all other dyes.

Mechanical Adjustments. Beating intensifies the shade and increases retention. This is also true of other refining equipment such as the jordan. Since these refiners will intensify the shade, care must be exercised when major changes are made in the setting of the jordan or changing the beating for fear of upsetting the shade. All such changes should be called to the attention of the color man when they are made.

Color Selection. Color selection is of prime importance and can mean the difference between profit and loss. A mill that has a good color man who knows his colors and can select the correct dye to give the fastness properties desired has a decided edge over less fortunate competitors. Many mills send requests to the dye companies so that they can take advantage of this free service and at the same time avail themselves of advice from specialists.

Before proper color selection can be made it is necessary to know what the paper will be used for. The end use will determine the color requirements. Dyes for paper rugs must be fast to light; soap wrap must be fast to alkali; deep shades on fruit wrap tissue probably have no requirements except shade and economy.

In many cases a mill cannot decide immediately what dyes should be used to match the shade in question. In this case, if the submitted sample was satisfactory it is often advantageous to use similar dyes. The dyes used to color the original sample can be identified by following a simple qualitative procedure which has already been published. This identification procedure takes advantage of the affect of simple chemical reagents on the color. Among the reagents used are 1 percent sulfuric acid, 1 percent caustic soda, 3 percent sodium hypochlorite, alcohol, etc.

In selecting colors the most important factor is common sense. Ask yourself what requirements will the paper have to meet and what colors will meet these requirements at the lowest possible color cost. In selecting colors use combinations of dyes with similar fastness properties. Do not use a fugitive basic dye with a fast to light color. The fading will result in a se-

vere shade change toward the shade of the fast to light color. The same holds true in regard to two-sidedness. If you use a non-two-sided color in combination with a two-sided pigment or dye the result will be a noticeable shade difference from one side to the other.

The pulp used will also influence color selection. If groundwood represents an important part of the furnish then inexpensive dyes should receive first consideration. Typical colors would be basic dyes, the acid oranges, Purpurine and Nigrosine or Black E Double. Groundwood fades readily and will fade irrespective of the dyes used for coloring.

The Standard Sample. The standard sample that is to be matched is a valuable item and should be treated accordingly. If it is large enough to provide an adequate sample, cut it in half and store one half in a clean envelope in a file. Use the other half as a working sample. As the sample is handled it will become dirty and soiled. It will often change in shade as a result of this handling treatment and the other half serves as a final reference sample.

As soon as a commercial match is accepted against the working sample compare it against the filed reference sample. If it is acceptable set this up as the standard. Each mill produces certain sheet characteristics which differ from the other mills. It is easier to judge shades having the same sheet characteristics than shades with different sheet characteristics.

The Standard Lamp. An important factor in shade matching is a constant source of light. The best light for judging shades is a morning north light. However, all paper mills work around the clock and therefore it is essential that a standard lamp be set up and preferably enclosed. This lamp should simulate a good north light and should be used for judging all shades.

Artificial light change is the property of appearing to change shade when viewed under artificial light in comparison with daylight. This property is characteristic of many dyes. Methyl Violet turns very red under artificial light whereas Methylene Blue turns very green. Very often, two shades may match under daylight but will appear very different under artificial light. This is another important reason for using one lamp one for judging shades.

Conclusion

The dyeing of paper is a fascinating field. It is a constant challenge to the color man to compromise and arrive at the best formula to match the shade with the required fastness properties. Good judgment based on a knowledge of the properties of the dyes is the keynote to a good color man.

Introduction

When Professor Jenness invited me to address the Pulp and Paper group at Maine I was pleased to accept because it was 39 years ago, September, when, as the first instructor in Pulp Technology, appointed under Dr. McKee, I gave the initial lecture in the Pulp and Paper Curriculum. Much water has run under the bridge since that day, and I have wandered far afield from the formal teaching profession but have never had reason to regret the time and effort spent in the initial phases of the development of the Pulp and Paper Curriculum, nor have I at any time lost interest in its growth from a modest beginning to its present size and influence. I here wish to pay tribute to the devoted service of my successors in the field, for the progress that they have made, for the obstacles which they have overcome, and for the ever expanding fields of work and service which their labors have insured.

Coarse Papers, Bag and Board

Albert G. Durgin[1]

B.S., University of Maine 1908; M.S., 1909; Registered Professional Engineer, Ontario; Member Canadian Institute of Chemistry, Technical Section, C.P.P.A.; TAPPI; Active in organization of the Pulp and Paper Courses at the University of Maine; Assistant Professor, 1914-1916; Chemist, then chief of Paper Section at the U. S. Bureau of Standards, 1916-1919; Superintendent of Operations-Research, Spanish River Pulp and Paper Co., Canada, 1919-1926; Engineer-Industrial Division, Canadian Bank of Commerce, 1926-1927; Superintendent—Spruce Falls Power & Paper Co., Ltd., Canada, 1927-1933-; Member Board Committee Technical Section, C.P.P.A., 1945; Chairman, St. Francis Valley Section, Technical Section, C.P.P.A., 1951.

The subject which has been assigned to me is *Course Papers—Bag and Board,* an overgenerous slice of the whole paper industry. No fine line of demarcation has been drawn between fine and coarse papers but the latter group which has wrapping and bag, for a foundation, definitely includes: abrasive asphalting, batting, beaming, blasting, cartridge and fusee, box liner, cable sheathing, core wrap, creping, die and plate wipe, embossing, envelope, file folder, filter, flameproof, greaseproof, gumming, impregnating or saturating, insulating, interleaving, laminating, metal protective, ordnance wrap, pad wrappers, printing, separating base, spinning, tag stock, tire wrap, towelling, tube stock, twisting, varnishing, water repellent, waxing, and wet strength grades, many in both M.G. as well as M.F. finish.

Obviously no one mill produces all of these grades but in general the Canadian mills producing coarse papers cover a much wider range than do their opposite numbers in the United States, not from choice, but of necessity. Coarse paper mills in the United States cater to the needs of 160 million people and, because of the size of the market, are enabled to make longer runs on a single weight and grade than is possible in the Canadian

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field with less than one-tenth of the population. In fact, some of the large Southern kraft mills have so streamlined their production that the mill operation approaches news production in continuity. In contrast, it is not uncommon in Canadian practice to change grade, weight or color five to six times in a 24 hour day on a single machine.

As previously stated, wrapping papers and bag papers form the backbone of the coarse paper industry and it is to the latter class that I propose to draw your attention. The bag paper field can be divided into two types of producing units, one producing grocery bags, millinery and notion bags, and specialties and the other devoted to the production of multiwall sacks. In connection with the former group, a recent issue of the *Mosstyper* carried the following under the caption "In the Bag."

> "When your grandfather used to take his pennies to the corner candy store for jelly beans, the odds are his purchase was packaged for him in a little hand made bag or cone of brown paper. For it has been a mere 99 years since the paper bag was first formed on an automatic machine, and but a few years earlier that hand operated bag makers first came into use. Credit for development of the first automatic bag machine rests with a Pennsylvanian named Francis Wolle, who was granted a patent on his device in 1852. The original Wolle machine formed the bag from sheets, but a scant half dozen years later he turned out an improved model which made bags in a continuous operation directly from a running paper web."

Grocery Bags

While the modern bag machine is truly a precision machine, and vastly improved over the original model, it still operates on the same basic principles as did its forebears. Grocery bags are merchandised in three different weights—light, medium and heavy—and in conventional sizes with indication of the carrying capacity. Thus, one-fourth, one-half, one, two, three pound bags, made in lightweight only, use paper weighing 25 pounds per ream, 24 x 36—500; four pound bags require 28 pound paper; five, six, seven and eight pound bags use 30; ten and twelve pound bags use 33 pound paper; 14 and 16 pound bags use 35 pound paper for lightweight, 39 pound paper for medium-weight, and 50 pound paper for heavy-weight grades; 20 and 25 pound bags use 37, 44 and 50 pound paper; 30 and 35 pound bags are not made in lightweight, they are made from 44 pound paper in medium-weight and from 50 pound paper in heavy-weight.

Every grocery bag bears a printed stamp circle in which appears the capacity of the bag, and printed circumferentially therein is the trade name which indicates the weight class and the manufacturer's name.

Productive rate per machine ranges from 1500 bags per hour in the one-fourth, one-half, and one pound weights to 8250 per hour on the 35 pound line. The same bag machine can be set up to produce duplex bags, in which instance mill rolls are mounted one behind the other and so fed that the two sheets enter the forming portion of the machine one over the other under uniform tension.

All sorts of combinations of color can be produced in duplex bags. For example, a kraft inner sheet may be combined with white outer sheet, or the reverse; or any desired combination of two colors of paper may be used. Bags of this nature, since 1928 when it became possible to print with aniline inks using rubber plates, in a rotary printing setup added to the fabricating equipment, frequently carry advertising copy for its "Buy Again" appeal.

Kraft paper for conversion into paper bags must conform to fixed specifications with narrow tolerances. While trade customs permit a plus-minus five per cent tolerance in basis weight, this quality factor must in fact be held well inside the tolerance limit because any increase over the specified basis weight reduces the number of bags produced per ton of product while underweight paper may be deficient in strength and lead to failure of the finished product in the field.

"Bag Finish" is a term well understood in the trade but difficult to define. An examination of specimens will show that it lies between rough and smooth, approaching the former. This quality is closely associated with caliper or thickness of the sheet. Uniformity in this factor is of paramount importance to insure satisfactory operation on the bag-making machine. Wide variations in thickness may lead to jamming in the bag forming process, thus causing loss of production and waste of paper.

Formation must be uniform. Excessively wild formation must be avoided because of the thin portions of the sheet are deficient in strength and hence more subject to failure under stress. Tensile strength must be maintained in both machine and cross direction. Tear resistance, as indicated by the Elmendorf tear tester, must be maintained at the highest practical level. Tradition also requires a uniformly high Mullen test. Porosity of the sheet is also of importance. Too low or uneven porosity point indicates uneven formation which may lead to failure of the bag. Sizing must also be controlled and maintained at a level high enough to insure reasonable retention of strength under high humidity conditions or when the container is exposed to varying climatic conditions such as rain, snow, sleet, etc. Where more than normal resistance to the elements is needed, or where the contained product is moist or hygroscopic in nature, it is necessary to use a bag produced from paper that has been treated in such manner as to impart wet strength characteristics to it. This is of particular importance, in super markets where pre-packaging is regularly practiced and, hence, where a standard bag would be weakened by prolonged exposure to moisture. Moisture content in the sheet must be uniform throughout and wet streaks must be guarded aganst since they tend to cause uneven adhesion when the bag is made. If the moisture is excessive it leads to the rejection of the finished product.

Control is exercised by:

1. Testing of paper as each set is made to insure conformity with standards.
2. Retesting of selected samples from each lot under controlled humidity conditions.
3. Retesting of any product found to be marginal in any respect.
4. Rigid rejection of sub-standard product.

For record purposes a complete history of each run is preserved on index cards (or other permanent record form) and a review of machine or mill performance on any run or on any past period is constantly available.

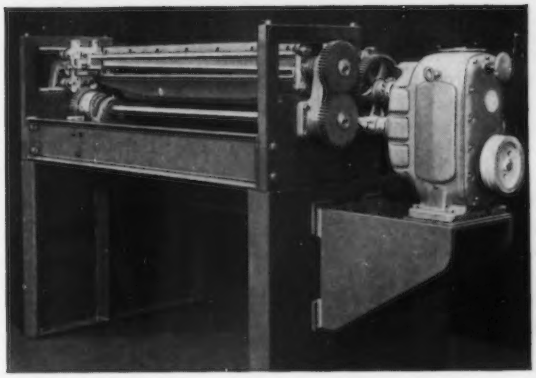
The winder crew is responsible for detection and elimination of holes while both machine and shipping crews are responsible for seeing that rolls containing corrugation, soft edges, etc., do not leave the mill.

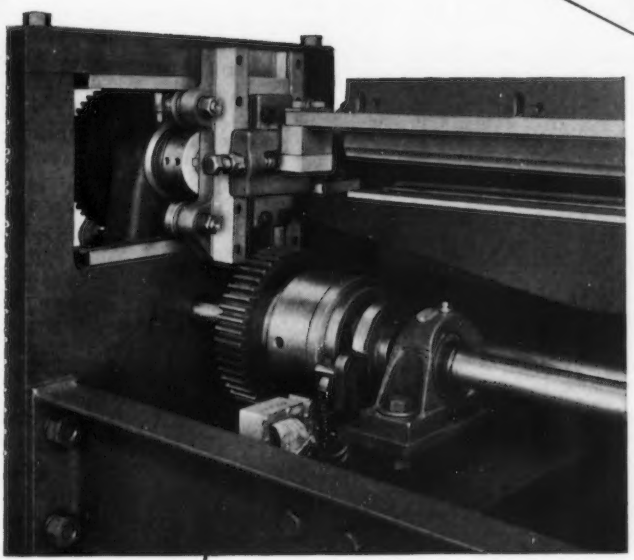
Notion and Millinery Bags

Reverting to bag manufacture, notion and millinery bags are wedge type, i.e., without gussets which characterize the standard grocery bag. These bags are designed for packaging of small or light weight articles. They are normally produced from 25 pound paper, frequently in color, and in either M.G. or watermarked grades. In almost every instance these bags are printed so that the maximum of advertising value can be derived from their use. The production rate on bags of this type is high, ranging from 200 to 800 bags per minute on notion and from 200 to 600 per minute on millinery, depending, of course, on the size of the bag under production.

Special purpose bags, like duplex

Egan





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Shear accelerates to web speed, provides scissor cutting action at speed, accelerates to avoid "humping" while upper blade is raised to clear web, then returns to start position.

Slitting attachment can be provided. The Traveling Shear gives accurate clean cutting of all "tough" materials.

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bags for packaging tea and coffee in which the inner sheet is greaseproof, are also produced on standard bag machines. Another speciality bag is the shopping bag which is formed without gussets and with a folded back top to which handles are stapled to provide easy means of carrying the unit when filled.

Multiwall Sacks

The displacement of cotton and jute textiles by paper multiwall sacks provides a classical example of the invasion of other industrial fields by paper and paper products. While multiwall sacks had been in production and use prior to 1939, the general field of bagging had largely been controlled by the textile industry, using cotton and jute as raw material. In fact, during the 1937-39 period, cotton counted this field its third largest customer, consuming annually some 458,760 bales. Urgent demand for cotton and jute for other purposes opened the door to rapid expansion in the paper field. Development followed on new development. Asphalt barriers introduced into the multiwall structure provided a satisfactory barrier against moisture vapor penetration and the development of wet strength papers permitted the stack to resist most hazards such as shipping conditions, climatic changes, rain, sleet, snow, salt water, blistering heat, freezing weather, etc. By 1942, more than 325 different types of commodities were packaged, stored, and shipped throughout the world in paper shipping sacks. Millions of bags have been used for commodities having fast hardening characteristics such as rosin and asphalt. These are poured into the bag in the liquid state at elevated temperature without injury to the bag. When cooled, these commodities harden within the bag. Countless bushels of potatoes are shipped annually to markets in sacks ranging in capacity from 10 to 50 pounds. Salt, sugar, and flour are shipped in 100 pound units. Rice, peas, beans, calcium chloride, chemical fertilizer, cement, lime, pigments and hundreds of other commodities ranging in density and characteristics are shipped in paper sacks.

Paper sacks are regularly used for the delivery of ice cubes in the domestic market.

The present trend is toward greater use of creped paper in forming the wall tube, partly to reduce hazard of breaking in transit and storage due to absorption of part of the force of impact by the creped structure, and in part to reduce transit damage and storage damage caused by slipping or chafing of smooth walled bags. The roughened surface also permits neater and more compact storage in warehousing.

Paper for conversion into multiwall bag is normally produced in 40, 50, 60, 70, 80, and 90 pound weight, the bulk of production being in the 40, 50, and 60 pound range. Typical specifications for this type of bag are given in *Table I* for the lower weights.

In producing the multiwall tube the requisite number of rolls, to produce a specified number of plys, are mounted on a back stand so arranged that friction as required can be applied to the shaft on which the rolls are mounted. Since the ultimate strength of the finished bag is dependent on having each separate wall in intimate contact with the remaining plys, uniformity in caliper and winding is of paramount importance. Presence of corrugations in the mill roll will produce slack contact between plys and a bag so made will fail in operation because stress in handling the loaded bag is resisted by less than the full complement of plies. Formation of the sheet must be uniform. A light streak is an element of weakness and the paper is more subject to rupture at this point.

The multiple plys pass the forming section where the tube is formed and adhesive applied. The tube continues to the cut off point where tubes of correct length are cut from the moving tube. The bottom of the bag is then sewn on and if valve loading is to be employed the top of the bag is finished.

Porosity as specified is also of great importance as some air must be vented through the walls of the bag when mechanical loading is practiced. Further, leakage of air through the bag prevents formation of air pockets and reduces the hazard of breakage in loading, transporting and storing of bagged product. Drop testing of loaded bags is employed by one bag maker as a practical control on quality of output.

Impregnating Paper or Board

An interesting product, employed in the manufacture of thermosetting resinous plastics either in flat sheets, or in various moulded forms, is impregnating paper or board. At this time I propose to deal only with the application in decorative product which finds application in table top covering, sink splash boards, kitchen working surfaces, bars, soda fountains, counters and counter facings, sleeping and lounge cars, and wherever else a smooth, colorful, clean, wear resistant surface is required. The finished product is hard, dense, strong, and tough. It is chemically inert, resists stains, and is not affected by alcohol, boiling water, cosmetics, and house-hold cleaning preparations, will not swell or shrink, and resists chipping, cracking and abrasion.

The impregnating sheet is a waterleaf one produced from well-cooked, thoroughly washed kraft pulp which has been given only enough pre-treatment to permit uniform formation on the paper machine and not enough treatment to reduce the absorbency of the finished product. It must be free of dirt specks, bark, fiber bundles or shives for reasons that will be developed later. The sheet must be free of light areas. *Table II* gives some typical specifications for the type of sheet required.

In producing board, the first step is the impregnating of the sheet. Normally phenol formaldehyde resin is used for the body of the sheet and melamine resin for the decorative top. The sheet is mounted on an unwinding stand and passed through a bath of resin at a speed slow enough to insure maximum pick-up of chemicals. The sheet may be dried by passing through a narrow chamber fitted with infra-red lamps (or by other means of obtaining controlled temperature) and allowed to cure for from four to ten days, and is then cut into sheets of proper size.

The first step in producing the board is to place on a highly polished metal plate: (1) One melamine treated backing sheet, (2) The required number, approximately 15, of saturated sheets to give an end product of standard thickness, (3) The sheet bearing the desired design, (4) A thin, opaque melamine treated top sheet, and (5) The whole pile is covered with a highly polished plate. That process is repeated until a pile approximately seven inches in height has been built up. This "build up" is then placed in a hydraulic press equipped with steam heated platens and pressure and heat are applied until the resin is plasticized and cured. The pressure is then relieved, the board removed and trimmed to size, after which it is ready for distribution.

Paper-Board Classification

Paper-board manufacture is divided into three main groups:

(a) Container grades for construction of shipping cases;

(b) Box board grades for construction of folding cartons and set up boxes;

(c) Grades for miscellaneous uses such as wallboards, tubes, and wrapping.

Container Board

Container grades are used in the construction of corrugated containers. The board used will be made with corrugated material which forms the backbone of the box, and liner board which forms the top and bottom of the

box board and which imparts toughness to the structure. Alternatively, solid fiber is produced by combining a number of layers of liner board to produce a board of desired thickness, rigidity, etc. Two grades are produced on fourdrinier machines: corrugating medium and F.K.L. (Fourdrinier kraft liner).

Corrugating material is produced from straw pulp, semi-chemical pulps, and from kraft pulps either 100 per cent or with admixture of groundwood in various proportions. It is normally an unsized waterleaf sheet and must possess the maximum degree of rigidity both with and across the grain. Corrugating material is normally produced on a Fourdrinier machine in .009 inch caliper although caliper is not restricted to 0.009 inches and a considerable tonnage is produced in 0.011 and 0.012 inches caliper. When made from straw, the standard weight per 1000 square feet, which is the standard of sale, is 30 to 32 pounds. If produced from kraft pulp or semichemical pulp, or a combination of both, the standard weight is 26 pounds per 1000 square feet. There has been an increasing tendency to manufacture corrugating paper from semichemical pulps produced primarily from hardwoods, thereby conserving the dwindling supply of coniferous woods for use in other grades of paper and board. Both straw and semichemical pulps give high crush resistance when subjected to the flat crush test, and both pulps, on analysis, show a high hemicellulose content. Hence, it is assumed that the rigidity factor is definitely improved by the presence of polysaccharides. When kraft pulp is produced primarily for conversion into either corrugating or liner board, it is customary to cook the pulp to as high a Roe-Genberg Chlorine Number as possibly, thereby obtaining a greater yield per unit of wood and at the same time producing a product more suited to board manufacture. The practice of hot refining of brown stock has been a forward step in this direction and a Roe-Genberg Chlorine Number of 16, or even higher, is not uncommon in mills where this practice is well advanced. Experience indicates that the harder the kraft pulp supplied to the paper machine the higher is the rigidity of the end product.

Fourdrinier Kraft Liner, which forms both the outside and inside face of corrugated boxes, is produced in calipers from 0.900 to 0.025 inches. The caliper most used, however, is 0.016 inches. In Canada, kraft liner is produced in both dry and water finish but the tonnage of the latter grade is much higher because the smooth surface has less tendency to scuff, or peel, in transit and is better, adapted to reception of high gloss inks when the box is printed.

The pulp used in the manufacture of kraft liner normally is a very free pulp having an initial Canadian Standard Freeness of from 700 to 750. While it is entirely possible to prepare this stock for the machine by treatment in the conventional beater and jordan, the power requirements to accomplish this are high. The same end result can be obtained with much lower power outlay through the use of disc refiners, such as the Sutherland and Sprout Waldron, equipped with proper discs for the purpose. In producing kraft liner, it is general practice to refine the stock while it is still on the alkaline side and then neutralize the alkali with sulfuric acid. Alum is used primarily for reaction with the rosin size just prior to putting the stock on the machine. There is not any country-wide agreement on the degree of refinement necessary and the head box Canadian freeness varies for 700 to 530, with the majority of mills operating in the 600 to 650 range. The demand for higher finish has been met in several mills by the introduction of a secondary head box, located in front of the primary head box and above the wire, which discharges onto the initially formed sheet and over which it forms a thin, smooth top surface. The stock furnished to the secondary head box is much more highly refined than that delivered to the primary head box, its freeness ranging from 390 to 500 Canadian Standard Freeness. The percentage of the total sheet passing through the secondary head box varies from a minimum of 13 per cent to a maximum of 20 per cent. Controlled pH at the wire varies from 5.8 to 7.0. The range of vacuum employed at various stages is:

Suction Boxes	5-8 inches	Average 6.8 inches
Couch	14-22 inches	Average 18 inches
First Press	18-23 inches	Average 20 inches
Second Press	17-20 inches	Average 18.7 inches

The degree of water removal at the wet end, as indicated by bone dry content is:

Couch	18-26%	Average 22.4%
First Press	26-31%	Average 29.6%
Second Press	32-35%	Average 33.5%
Calenders	92-94.6%	Average 93.6%

TABLE I
TYPICAL SPECIFICATIONS FOR MULTIWALL BAG PAPER (LOW WEIGHTS)

		Basis Weight	40# (24x36—500) (Tolerance Plus-Minus 5%)	50# (24x36—500) (Tolerance Plus-Minus 5%)
Elmendorf Tear	Mach. Direction		100	125
	Cross Direction		110	140
Schopper Tensile	Mach. Direction		15# per ½" width	18¾# per ½" width
	Cross Direction		8¼# per ½" width	10½# per ½" width
Schopper Stretch	Mach. Direction		2%	2½%
	Cross Direction		4%	5%
Moisture		7-8%	(To be determined as made)	
Ph—		6.7/7.2		
Ink Penetration, 70°			Average 30 mins.	Average 45 mins.
(Carter's Midnight Blue)			Min. 10 mins.	Min. 15 mins.
Porosity (Gurley)			Not to exceed 75 sec. for passage of 300 cc.	Not to exceed 90 sec. for passage of 300 cc.

Caliper to be uniform across sheet.
Each roll to be wound uniformly tight across sheet.
Splices to be made with Copaco or gummed tape and flagged at both ends of roll.
Not more than three splices to each roll.

TABLE II
SOME TYPICAL SPECIFICATIONS AND PROPERTIES FOR KRAFT IMPREGNATED PAPER USED FOR MAKING LAMINATED BOARD

Thickness	.009"	.011"
Basis Weight	70 P-M 2	100 P-M 3
Moisture	5%	5%
Density	9.0	10.0
Mullen	75# Min.	80# Min.
Ash Content	1% Max.	1% Max.
Porosity	100 cc. in 5-10 sec.	100 cc. in 5-10 sec.
Drop Test	2 sec.	2 sec.
Finish	Rough	Rough

REQUISITE PROPERTIES

Formation must be uniform, excessive wildness avoided, otherwise uneven pick-up may result.

Shives and foreign particles must not be present due to their water absorption effect.

Finish must not be too high, or smooth because this may cause delamination when punched or fabricated. Best board is obtained with rough finish.

Weight must be uniform to insure uniform resin pick-up. A variation of 3% in weight will change resin pick-up by 5%.

Ph influences characteristics of final product, i.e., Ph considerably on the alkaline side may result in insufficiently cured laminate.

Ph considerable on acid side tends to produce brittleness particularly with melamine or urea formaldehyde resins.

Many of the larger southern mills producing kraft liner pulp have installed a breaker stack which consists of a brass or chrome plated bottom roll and a rubber covered, or hard neoprene, top roll. This eliminates or reduces wire mark, improves drying, and increases overall machine productive rate by over five per cent. The water finish is obtained by application of a starch-wax emulsion at the wet stack by means of a water box. In some cases, excess moisture is removed by passing the sheet over a train of two or three dryers placed between the stacks. The presence of this wax gives a hard surface capable of taking high gloss inks which results in a much more attractive package. The efficiency of this film is determined by photovolt gloss meter readings on standard oil spots. A comparison of products from eight large producing mills shows that the oil resistance varies from a minimum of seven seconds to a maximum of 26 seconds. The high value denotes the better printing surface.

Two container board grades are produced on a cylinder machine, namely *cylinder kraft liner* and *test jute.* Cylinder kraft liner is produced in four calipers: 0.016, weighing 51 pounds, .020, weighing 66 pounds, 0.025 weighing 80 pounds and 0.030, weighing 93 pounds, all on a one thousand square feet basis. Cylinder kraft liner, in general, is competitive with Fourdrinier kraft liner in the production of corrugating boxes. Test jute is a trade name only since the product itself contains no jute fiber. The top liner is regularly produced in three colors: natural, jute grey and brown, but for special purposes a variety of shades are merchandised. These colors, in the main, are produced by stack staining. In Canadian practice, test jute is manufactured in three calipers: 0.016, weighing 62 pounds, 0.025, weighing 94 pounds, and 0.030, weighing 103 pounds, all per one thousand square feet. Corrugating containers employ different types of flute in constructing the box and a combination of "A" and "B" flute are used.

The solid fiber box is made by combining a multiplicity of sheets of kraft liner to provide the requisite thickness. A solid fiber box possesses a higher degree of rigidity and is capable of more frequent re-use than the normal corrugated container. The normal number of re-uses for the corrugated container is seven, whereas the solid container used for the same purpose is capable of from 15 to 20 returns. Numbers appearing on the cover are punched to indicate the number of trips actually made. The solid fiber container is a premium product.

Boxboard

In dealing with boxboards, the first grade to consider is the *non-folding board* which finds its industrial use primarily in the construction of "set-up" boxes. The ordinary shoe box is a typical example of this. It is possible to produce decorative containers by application of special paper of different types as a cover medium. Non-folding boards are produced in calipers from 0.025 to 0.050 inches and in three finishes: low-finish, medium-finish and high-finish. Non-folding board is principally merchandised in sheets and the trade customs specify the number of sheets 30 inches by 40 inches per 50 pound bundle and the weight per 100 square feet of the board supplied.

Folding boards are used primarily in the manufacture of folding boxes of which the ordinary suit box is a fair example. These boxes have the advantage of occupying relatively little space and are easily assembled in box form as required for use. The range of calipers of folding boards if from 0.012 to 0.040 inches and the finishes range, in most calipers, from low through medium to high. Folding boards are produced in a wide range of colors to suit customer's requirements although the shades most commonly encountered are either brown or gray.

Bleached manila lined board finds its use primarily in the manufacture of soap cartons. It is produced in a range of calipers from 0.015 to 0.040 inches and mainly in the lighter weights. A very smooth surface is normally required because most of the boxes made from bleached manila lined board carry elaborate advertising.

A still higher grade in Canadian practice is *patent coated board* which possesses a smooth white surface on either one or two sides as specified. Patent coated board, one side, is produced in standard range of calipers from 0.012 to 0.040 inches, whereas the range for patent coated, two sides, is from 0.012 to 0.028 inches. A typical use for patent coated board in the Canadian industry is in the manufacture of cigarette boxes.

The Cylinder Board Machine

The problem of producing a sheet of board on a cylinder machine is vastly different from the problem of producing a sheet on a Fourdrinier machine. In essence, the cylinder sheet is made up of top liner, sometimes an under liner, filler and bottom liner. What happens, therefore, is that the cylinder board operator takes six or more wet sheets of paper made from at least three different furnishes, piles them together step-wise and produces a composite whole without the use of adhesives or any other agent excepting pressure and water. Moreover, if these sheets do not form a composite whole, ply separation will result and the product is then not saleable and has to be culled. The first problem in cylinder board manufacture is stock preparation. In the simplest case, three different individual furnishes have to be treated. These are as follows:

(1). The *top liner,* which will become the outside surface of the finished container. This naturally is of select stock. In the mill in which I am associated, prime kraft pulp is utilized with or without the admixture of groundwood pulp depending upon the grade to be produced. Whatever stock is used it must be treated in such a manner that a uniform smooth surface will be obtained on the finished board. It must be sized to provide the requisite degree of resistance to moisture penetration as well as to insure that the sheet is resistant to peeling and scuffing when the finished box is subjected to the hazards normally encountered in transportation and/or in storage. The pH must be controlled within relatively narrow limits and it is of vital importance that the sampling point in the preparation cycle be select and adhered to, otherwise the pH tests are of little or no value. The freeness of the sheet must be controlled because if the stock is too slow the sheet will close up too tight to permit the passage of water from the inside of the sheet to the atmosphere in the drying operation and ply separation or "feather-bedding" will result. On the other hand, if the sheet is too free, another set of troubles develop which will have an equal adverse effect on the finished sheet. Stock preparation in the board mill is largely performed by jordans or similar equipment and, inasmuch as both jordan bars are subject to constant slow wear, the adjustment at this point in the cycle requires constant and thoughtful supervision.

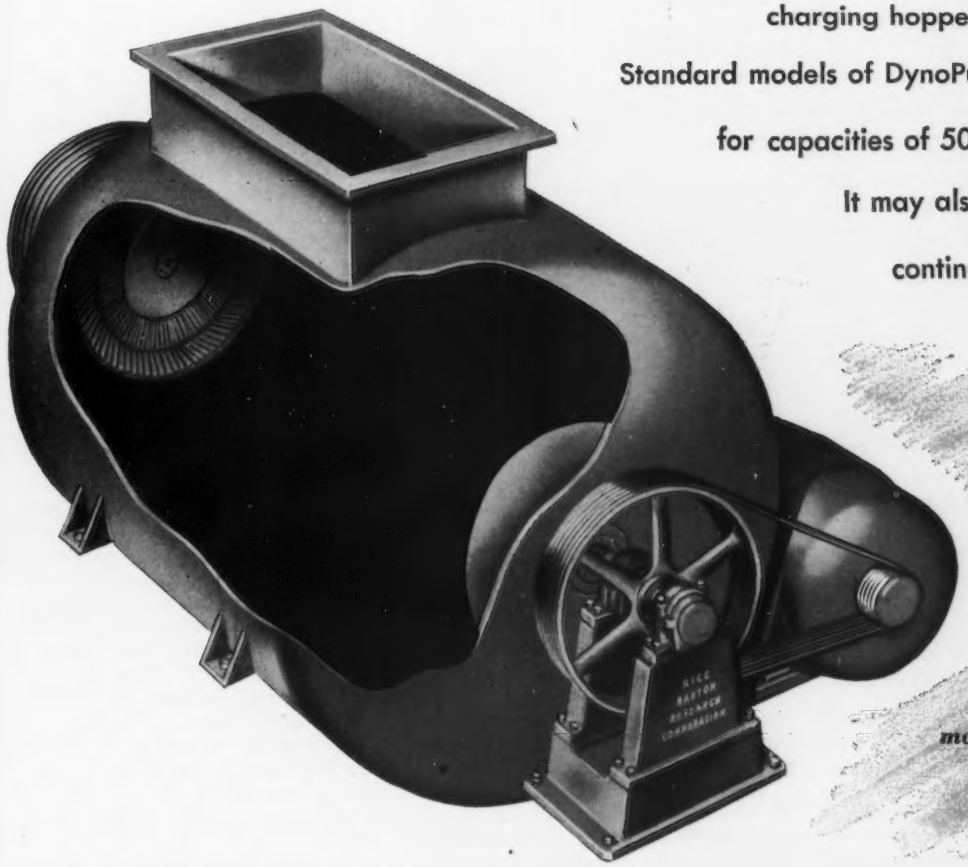
(2). The *filler stock* in most board mills is produced from waste papers and waste boards. In a few instances, similar to our own, the board mill acts as a scavenger, utilizing both groundwood screenings and kraft pulp screenings, with or without the addition of waste papers. Depending on the quantity of stock available in every case, the filler stock has to be refined until it reaches a point where the sheet formed from it will be compatible with the liner sheet.

(3). The treatment of the bottom

RICE BARTON DynoPulper

is comprised of a horizontal circular vat, having two DynoPellers. Stock may be charged all at one time, in bale or loose form, through the topside charging hopper.

Standard models of DynoPulper are designed for capacities of 500 to 2000 pounds. It may also be arranged for continuous operation.



Laboratory size models are available.

● The DynoPeller

is the heart of all DynoMachines. Its concave face is lined with rough, hard carbide particles. As the DynoPeller rotates it causes a suction at its center that pulls the stock toward it. Centrifugal force then causes the stock to flow rapidly over the rough carbide particles under a gentle hydraulic pressure. This effective dynomizing action completely disintegrates the stock . . . separating each fiber from its neighbor while maintaining its original length.

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liner is essentially similar to the top liner treatment.

While freeness of stock is of paramount importance within a single mill, there is no general standard of freeness that can be definitely applied to all mills producing the same grade of board. In a recent survey conducted by the Board Committee of the Canadian Pulp and Paper Association covering all Canadian board mills and some American mills, stock freeness of liner stock was found to vary from 110 to 441 points, Canadian Standard Freeness. Similarly the range for filler stock was from 207 to 583 points. The minimum variation between filler and liner in a single mill was 16 points and the maximum variation in a single mill was 250 points. The average variation over all mills in the survey was 117 points.

After the stock has been prepared, it is delivered to the screens, one of which is required for each cylinder on the board machine. Since the feed of accepted stock from the screen, mixed with the proper proportion of white water to give the desired consistency, is pumped directly to the vats, the quantity of stock fed to each screen must be controlled and the type of flow line to the screens, and the method of control of flow, are of importance.

Since many cylinder machines are compelled to operate over a wide range of board weights and with equally wide variations in type of stock, a wide range of flexibility must be provided and the screen should be efficient in removal of short, chunky fiber bundles and foreign materials. Provided this is not accomplished in the screening operation, excessive drying will be required to compensate for this deficiency, with consequent increase in production cost through added steam used and through reduction in the legitimate amount of salable water in the board. Further, the quality of product is adversely affected by overdrying.

There is no agreement in the industry as to the type of vat that is flexible enough to cover the wide range of grades and weights required in the present market nor is there uniformity of opinion as to the best type of approach flow. The problem is essentially this: stock in transit to the vat must travel with sufficient velocity and turbulence to prevent flocculation but once delivered to the vat the stock must reach the cylinder on which the sheet is formed with a minimum of turbulence. In general there are two types of vats: (1) direct or parallel flow vats in which the flow of stock is in the same direction as that in which the cylinder is moving, and (2) counter flow vats in which the direction of flow is reversed. The essential requirements of a vat are as follows:

1. All components of flow must be intimately mixed.
2. Air must not be entrained.
3. The vat feed must be steady.
4. The flow must be spread across the machine with exact evenness.
5. The mould head (i.e. the difference between the level of the stock outside the cylinder and the level of the white water inside the cylinder) must be subject to control.

The freeness of the stock is of importance. With slow stock the rate of drainage through the cylinder wire is slow and the mould head is relatively low. As stock becomes free, the drainage rate increases and the mould head increases. If the stock is so free that the maximum obtainable mould head is exceeded, the stock will roll on the surface of the cylinder and formation of the sheet will be poor. The cylinder wire must be kept clean and this is accomplished by use of a shower. Three types of showers are possible:

(1) High volume—low pressure.
(2) High pressure—low volume.
(3) Oscillating

The consistency of stock in the vats, as disclosed in the survey of the mills, varied from 0.139 to 0.612. In most mills the maximum was below 0.475. If machine speed is low then vat consistency will have to be kept low but with increase in speed the stock consistency must be increased because the drainage through the cylinder wire, within narrow limits, is independent of consistency.

Some mills produce an artifically high freeness and increased drainage rate by heating the stock in the vats, the survey showing a range from 41 to 127 degrees Fahrenheit. When high vat temperature is employed, the mill system must be closed to prevent loss of white water containing heat and thus avoid excessive cost in maintaining high temperature of the stock.

The sheet is couched from the cylinder to the felt. The importance of the role played by the felt in cylinder board operation cannot be overemphasized. It functions not only as a conveyor in wet end operation but each square inch of the felt must, remove water. Not only must the felt function in this respect but it must impart the least possible felt mark to the sheet because once a felt mark has been imprinted in a wet sheet it is almost, if not completely ineradicable. The felt must be so constructed that felt hairs must not be transferred from felt to sheet.

The prime function of the wet end of a board machine is to deliver a level, well-formed sheet to the dryers with the lowest possible water content because it is obviously more economical to remove water mechanically than by use of steam.

The sheet of cylinder board which has been couched off the cylinders adheres to the felt as a soaking mass and is conducted toward the presses. In most mills it is subjected to treatment designed to remove some water en route. In sixteen mills reviewed the following conditions were found:

Three had no suction equipment

One had suction boxes only

One had suction felt rolls

Two had extractor rolls

Two had extractor roll plus suction boxes

One had extractor roll plus suction extractor

One had extractor roll plus suction extractor plus suction boxes

One had extractor roll plus suction drum roll

One had extractor roll plus suction drum roll and suction baby press

Two had suction drum roll plus suction boxes

One had extractor roll plus suction extractor roll plus suction baby press plus suction main press.

After passing the section where suction is applied, the sheet enters the primary press section between top and bottom felts. The primary press section consists of from three to eight pairs of press rolls, generally rubber covered. There is a wide range of density in the rubber covering of these rolls from one mill to another. In some mills a constant nip pressure is held throughout the train of presses; in others there is an increasing gradient throughout with maximum pressure held below the point where there is hazard of "checking" (fine cracks) or "blowing" (ply separation). Leaving the primary press section the sheet passes through the main presses which may be either plain presses or, in most modern installations, suction presses. In mills under review, the main presses varied in number from two to four but in most installations the conventional three presses were found. Only one of the machines was equipped with predryers placed between the second and third press and these were heated with flash steam from the dryer train. The function of the predryer is to heat the sheet and to increase the fluidity of the contained water before the board is subjected to final pressing. In operating predryers on a heavy sheet, necessarily at low speed, there is danger of overheating the wet sheet to the extent that liberated steam ruins

the formation, actually exploding the sheet.

In the survey, it was found that the efficiency of water removal by pressure and suction varied over a wide range from mill to mill. Sheets entered the dryers carrying from 61.0 to 74.2 per cent of water whereas in the mill equipped with predryers the sheet entered the dryer section containing only 56.6 to 56.75 per cent of water, which was by far the most creditable performance. This divergence in performance points out a fertile field for development of improved wet end practice in board manufacture.

With such variation in moisture content entering the dryer train, it is obvious that the weight of water to be removed in the dryers per pound of finished board would show wide variation. In the most efficient unit 1.07 pounds of water per pound of board was evaporated and in the poorest operation 2.70 pounds had to be removed per pound product. Percentagewise, the additional water evaporated in the poorest case compared to the best performance was 152.5 per cent greater. The pounds of water evaporated per square foot of dryer surface ranged from a minimum of 1.47 to a high of 2.34. This means that an improvement of 59.2 per cent in performance would be required to bring performance to parity.

Drying of board is frequently the bottle neck in production. Hence the comparison of production per square foot of total dryer surface is a valuable unit of measure. This varied from a low of 0.702 pounds per hour to a high of 1.80 pounds per hour, so that to reach parity an improvement of 157 per cent would be required.

Heated air is usually introduced throughout the dryer train. The volume supplied is variable ranging from a low of 12,000 to a high of 75,000 cubic feet per minute. The reason for introduction of the air is obvious. The temperature of the heated air supply ranged from 110 to 230 degrees Fahrenheit and the humidity of the supplied air ranged from 2.21 to 18 per cent.

Conclusion

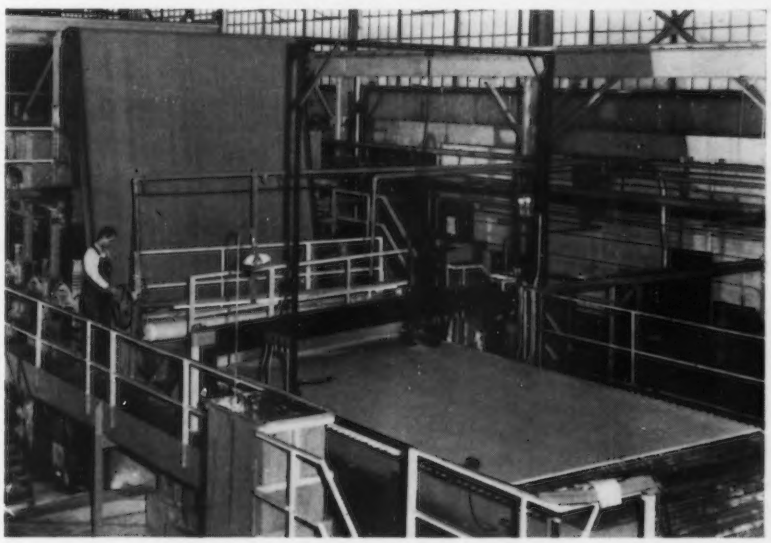
This wide variation in operating practice in mills shows that in board, as in paper, the industry is still practicing as an art rather than a science, and that the practice in any single plant cannot be transferred into any other plant and be expected to function perfectly. In other words, commercial practice from mill to mill is identical in principle but in practice the degree of attention given to each of the many variables which enters into the operation varies with local conditions, types of equipment, and so forth.

Many cylinder boards are treated by water box application at the calender stack to produce the desired finish. The agent used may be water alone, but is more commonly a starch solution, either plain or with the addition of emulsified wax and/or such materials as polyvinyl alcohol, carboxy methyl cellulose, sodium alginate, etc. In some cases polyvinyl alcohol or carboxy methyl cellulose or sodium alginate is used directly in water solution.

Stack operation may be further complicated by application of dyestuff, either alone or admixed with the other additives to calender color or to stack stain the surface of the board, a procedure that normally is more economical than beater dyeing to achieve the same end result.

Acknowledgment

In preparing the material for this presentation I have had recourse to data in process of preparation for publication, private communications, and the very generous help of my colleagues.



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Coarse Papers

P. S. Bolton

Graduated University of Maine, Class of 1913; worked as chemist in sulphite, soda pulp mills and in rag content paper mills until 1918; introduced chlorinated starch for tub sizing into the paper industry for Huron Milling Co.; became a partner in Mansfield, Bolton & Kent. In 1943 joined Robert Gair Co. to organize Research Department and currently is research and technical director of that company.

General

The subject of coarse papers is not a narrow one. It covers a wide range of papers amounting to over one-half of the 26 million tons total production of paper and paperboard. No one man can be expected to have a detailed knowledge of all the grades being produced and sold and in order to narrow the field I am passing over many grades with only a nod of recognition, and confining my remarks to those used in packaging. This does not mean that the building and insulation paper production of 1,400,000 tons is not substantial and important or that it is not interesting that 269,000 tons of paper towels were used in 1951. It only means that I know nothing about such grades beyond the fact that they are manufactured and sold.

Wrapping Paper

By paper or paperboard used for packaging I mean those grades whose prime function is to protect some other material from dirt, water, breakage, etc. The first and simplest package is, of course, one wrapped in paper and fastened with string. This you all know. Originally wrapping paper was a sheet which had already served some other purpose. About the first example, which incidentally is still in use, was the discarded newspaper. A century or so ago while newspaper was still made from rags it made a very good wrapping paper. Today's groundwood sulfite sheet leaves much to be desired if you want to protect the contents of your parcel against a heavy rain.

Wrapping paper, which consumed over 800,000 tons in 1951, came into its own with the invention of the kraft process which was introduced in Canada in 1907 and in the South in 1911. Today wrapping paper is produced from kraft pulp on the high speed Fourdrinier machine and with high burst and tear factors and can be made with high wet strength and water resistance. It can be printed, colored and otherwise decorated. Its use is shrinking. In 1951 the tonnage produced dropped 18 percent, probably due mostly to the increasing use of paper bags.

Paper Bags

The paper bag got its start as a rolled up tube closed at both ends and used to package tacks. Like wrapping, the great growth in the acceptance of paper bags followed kraft pulp. Kraft had the high strength characteristics and the cost factors to make a suitable paper for bags. There are basically two types of paper bags produced, grocery bags and shipping sacks.

These both showed large increases in usage in 1951. The grocery bag production grew 12 percent, to 850,000 tons, while the shipping sack gain was 20 percent, to 800,000 tons, or over two billion sacks. Like the wrapping paper you are quite familiar with the grocery bag. It is generally kraft pulp beaten to good strength factors and made on a Fourdrinier machine at high speed, but generally without wet strength characteristics. Wet strength and water resistance can, of course, be built into the paper at additional cost. In addition to the grocery bags, there are general retail store bags for notions, millinery, dry cleaner bags, liquor bottle bags, bread bags, etc., which constitute about one-third of the total.

Shipping Sack

We now come to the shipping sack. Again the acceptance of these containers follows the development of kraft pulp. The shipping sack, generally of the multi-wall type, has had a tremendous growth as a replacement for the cotton or jute sack for shipping bulk materials such as starch, sugar, and dry bulk chemicals. The largest portion of this replacement of cotton and jute has been in the multi-wall type of sack. Multi-wall simply means from two to five bags closely fitted inside each other. The use of multi-wall sacks has grown from 500 million in 1942 to 2 billion in 1951. This construction allows a wide selection of papers for each bag. The inner bag can be lined with an inert resin such as polyethylene so that a corrosive material will not attack the paper. Another layer may be an asphalt combined duplex sheet, either plain or creped, to protect the contents from water or water vapor, and the outer bag may be made of a wet strength paper which will not tear if wet. Something on the order of 120 million tons of bulk commodities are shipped yearly in these multi-wall bags. For some commodities such as flour the bag is made from a coated paper so that it can be printed in colors if desired. One company, The Union Bag and Paper Company to whom I am indebted for the foregoing figures, produces over 1000 tons of bags every 24 hours.

Fiber Drums

Before getting to the shipping containers, both solid fiber and corrugated, and folding boxes, I do want to call your attention to the fiber drum. This is the fastest growing package made of paper. This type of container, which incidentally can be used for shipping wet and semi-liquid materials, by using something such as a polyethylene bag as an inner package, evolved from the paper mailing tube. These mailing tubes were first manufactured about 1865 and were convolute, or straight wound paper tubes. From the mailing tube in about 1870 came the textile tube, still convolute wound on a mandrel, and about 1880 a tube with slip-cap covers was used for baking powder. The spiral-wound tube, which produces a tube continuously from paper in the roll was developed about 1903. Cans made of both convolute and spiral wound tubes were used mostly for small packages. The shortage of steel during the Second World War had a tremendously stimulating effect on the development of the present fiber drum. Closures of various types were copied from the steel drum or developed par-

ticularly for the fiber drum. Special linings to resist chemical action of the contents were worked out and today these drums are very largely adopted by the chemical and dyestuff industries. They are generally made from either so-called cylinder kraft, a sheet produced from reworked kraft paper having a strength and density particularly suited to this type of container, or from a virgin Fourdrinier kraft sheet.

Containers and Container Board

This brings me to containers, both solid fiber and corrugated, which my company manufactures. Container board production, solid fiber and corrugated, in 1951 was 5½ million tons. During the past eight years I have been exposed to the problems of this and the folding boxboard industry so that by a sort of osmosis I have absorbed some knowledge of them. I am hoping to be a little more specific in this portion of my talk.

Solid fiber board used to produce the solid fiber box is made by laminating several sheets of paperboard, .016 or .020 inches in caliper, with an adhesive to produce a board of .080 to .100 inches thick. The adhesive may be starch, starch and urea, or a polyvinyl alcohol. The combined board is slotted and creased so that it will set up as a box into which a product can be packed. The various plies can be kraft liner board, jute lined board, chip board, kraft paper combined with asphalt, etc. Kraft liner board is made on a Fourdrinier machine from virgin kraft pulp. The Fourdrinier is usually equipped with a dual head-box so that the top side of the sheet is composed of a better beaten stock than the balance resulting in an improved finish on the top side of the sheet. Kraft liner board is made in the following weights and calipers with standard mullen test specifications.

Caliper	Weight per 1000 Square Feet	Mullen Test
.014	42	100
.016	47	100
.023	69	135
.030	90	170

In some cases the 90 pound sheet is made by combining two 42 pound sheets with an adhesive. This is done largely because the 90 pound sheet is not as economical to run on the paper machine as the lighter weights.

Jute liner is made on the cylinder machine, usually six-ply with the top ply of virgin kraft or high grade kraft waste paper and the other plies of strong waste paper. It is made in these weights and calipers.

Caliper	Weight per Thousand Square Feet	Mullen Test
.016	60- 64	100
.030	100-120	150

Figure 1—Two-Piece, Telescopic Container

Chipboard is an all waste paper cylinder machine sheet with an outer ply of news, old corrugated boxes or combinations of other waste papers. It is made in various calipers but usually without a mullen specification. If the other components are sufficiently strong it can be used as one or two plies in a solid fiber board.

The solid fiber container is used for domestic shipment only when the material to be packed requires more protection than can be obtained with a corrugated container. It is considerably heavier, which means higher freight costs, and is more expensive to manufacture. More actual fiber is used to produce a case of a given size. Consequently, the volume for domestic shipment is comparatively small.

At the start of World War II thousands of tons of foodstuffs and other materials were shipped abroad in the ordinary corrugated box which had long since been widely adapted for domestic shipments. Much of this tonnage was unloaded on docks and on open beaches with no protection against the weather. It was often piled outdoors without even a tarpaulin to protect it from the elements. If you have ever picked up a corrugated box that has been standing in a damp cellar for a few weeks you can realize that the losses under tropical conditions were fantastic. The armed services were at their wits end. It was impossible to cut timber and produce enough wooden boxes for the job and in some instances the wooden box was not the solution either.

Figure 2—Counter Display, Related Individual Carton

The problem was passed to the manufacturers of solid fiber cases, and a group of these mills organized a technical staff to study the problem. No one at the start considered it possible to make a box from paper which could be submerged for 24 hours and continue to protect its contents. The original specification called for a board which would not delaminate if submerged for 2½ hours. Cases made from this board failed in service and the specifications were then raised to 24 hours. Laminating adhesives were worked out and thousands of tons of the so-called V-board were produced. Cases of canned foods in V-board, metal strapped, would withstand 24 hours pounding in the surf and emerge still protecting the contents. These cases were not waterproof. When removed from a submergence test water would stream out of each corner. Later by sealing them with waterproof tape at all corners and seams they were made waterproof as well. It is interesting to note that the technical work in developing the V-box was so well done that with only minor changes the same specifications are in force today for shipments to Korea. Research work is going forward to further improve

Figure 3—Shipping Chest for Fresh, Whole Blood

the V-box. We are being asked for insect and rodent repellent board, moldproof board and for a board which will not delaminate at any temperature between —60 and +160 degrees Fahrenheit.

Historically, like wrapping and shipping sacks, the development of the V-case and the corrugated case really begins with the invention and wide adoption of the kraft process. Some solid fiber cases were made as early as 1902, using so-called jute board. Jute, by the way, may have originally contained some actual jute fiber added to give strength. This was eliminated in favor of kraft pulp very early but the name "jute" has continued to this day. You may be interested in the fact that this type of board was made here in Maine at Benton Falls and South Windham in the late 1890's. In fact, South Windham has some claim to its invention. As we have already said, today's "jute" is made on cylinder machines using waste paper, with possibly some virgin kraft in the top liner or face of the sheet. During the Second World War paper making fiber was a very short commodity and every manufacturer of paper products did his best to produce the desired quality with the minimum of fiber consumption.

In the jute industry the standard weight for .016 point board with a mullen of 100 was 64 pounds per thousand square feet. This weight was gradually reduced to as low as 52 pounds per thousand square feet without sacrificing the mullen strength and considerable jute is produced today at this lower weight.

Kraft liner board for use either in solid fiber or corrugated boxes is much newer than jute. It was first produced experimentally at Bogalusa and commercially on a cylinder machine by Hummel-Ross Company in 1923. The first Fourdrinier kraft as we know it now was made at Monroe, Louisiana in 1926. With the establishment of the kraft industry in the South, the growth of this type of liner board came into its own. Since its start in 1926, to 1951, it has grown from 37,000 tons to 3,400,000 tons. Due to its low cost and high strength qualities it has led the field in the production of high quality corrugated containers. During the war the producers set up the Fourdrinier Kraft Institute which has fostered much of the research work which produced the improved corrugated box in use today.

Corrugated Containers

The greatest volume of goods for domestic shipment are packed in the standard type of corrugated container which is printed, slotted, creased and stitched or taped, on one seam, so that it can be shipped flat. On arrival at the customer's plant, it is set up, packed, and sealed for shipment. The size, shape, and general construction is worked out to best pack the product, very often on automatic machines, and protect the contents.

A typical corrugated case is made up from a corrugated board having kraft liners weighing 42 pounds per thousand square feet and the corrugated portion, the so-called .009, weighing 26 pounds per thousand square feet. There are three types of flutes, A, B, and C. The "A" has 36 flutes per foot, the "B" 50 per foot, and to make things a little less easy the "C" falls between with 42 per foot. Such a combined board will test 200 on the mullen. For an adhesive, originally silicate of soda was used and is still used but it has been replaced quite widely with special starch combinations. One of these is a mixture of cooked and uncooked starch. This mixture has a viscosity which allows it to be applied to the tips of the flutes in passing through the corrugating machine where the heat of the corrugating rolls swells the uncooked starch to give a quick tack strong enough to hold the flutes in place until the paste is set.

I might digress a bit at this point to show you how much research work can go into the development of a new outlet for the corrugated shipping container. As you know the citrus crop has in the past been packed in the so-

Figure 4—Folding Paper Boxes

called Bruce box, a wooden structure which is open for ventilation. This box normally holds 1 3/5 bushels weighing 90 to 95 pounds. Corrugated boxes of a size to hold this volume and weight were not strong enough to stand shipping. In addition, a closed box of ordinary corrugated board resulted in fruit spoilage. After considerable experimentation a box to hold 4/5 bushels was developed and attempts made to ventilate it. The growers were firmly convinced that such ventilation was necessary. Holes to provide this ventilation, however, weakened the box to the point of failure.

In order to give the box added rigidity particularly under 85 to 90 percent humidity, experiments were carried out using melted sulfur impregnation and finally a method of impregnating the .009 corrugating medium was worked out. Even this more rigid box did not have sufficient strength if it was perforated to give ventilation.

At about this stage of the game Mr. B. A. Weathers, who had been working on the problem of fruit decay, suggested that a combination of diphenyl, wax, etc., if applied to the corrugated board would retard decay in the boxed fruit. This proved to be the case, but the treated board had a very objectionable odor which would transfer to the fruit. A research project was set up at the Institute of Paper Chemistry to solve this problem with the result that counteractants to the diphenyl odor were found and the present phenodor formula developed. This was not only satisfactory from the odor standpoint but it was very much better in preventing decay.

Progress up to this point had given the sulfur impregnation of the .009 for rigidity at high humidity and the phenodor prevented decay. The smaller 4/5 bushel box was agreed on. However,

Figure 7—Foiline, Plastafol and Tubbord Carton

Figure 5—Gair-Reynolds Foiline Cartons

the standard type of slotted container was still not good enough and efforts were now turned toward a box which could be shipped in sections and set up on the job. Efforts along this line produced the box you see here. This box carries fruit with less shrinkage, less spoilage and while it may be still further modified is acceptable to the citrus fruit industry.

This research work obviously was expensive and could only be financed by such a group as the Fourdrinier Kraft Institute. Each member contributed and all members benefited.

To return to the standard type of corrugated container, the first corrugated board was made without liners and was used as a cushioning material for packing. In 1894 Thompson and Norris produced the first board as we now know it, and after some patent litigation this company and Robert Gair, under a license from Thompson and Norris, had more or less a monopoly for several years.

The original corrugating medium or nine point, so-called because it is generally .009 inches thick, was made from straw. In 1927 extracted chestnut chips were pulped and the paper produced was used for corrugating. Incidentally, this was the first semi-chemical process. Today there are several types on the market, kraft from the South, some chestnut, some made from waste paper, and finally a high yield semi-chemical sheet. This last is becoming the standard of the industry. It is generally made from hardwoods such as poplar or gum, using a number of variations in cooking to produce yields of 75 per cent from the wood. Because of its moldability under the heat and pressure of the corrugating rolls and its rigidity after molding, it has been very widely adopted. Production has increased since its start in 1946 to 825,000 tons in 1951.

Today the corrugated container is used for packaging all sorts of materials ranging from soap powder and cereals to furniture, radios, etc. Its use is constantly expanding into new fields such as the citrus fruit I mentioned. We, in the industry, are working to give the board new characteristics such as insect and rodent repellency, moldproofing, further resistance to high humidity and refrigeration as well as new designs to fit use requirements. During 1951, 70 billion square feet of corrugated board were produced, enough to have a street 500 feet wide, 26,400 miles long, or a distance greater than the circumference of the earth at the equator.

Aside from packaging it is also finding other uses such as pallet legs. Pallets of the one trip type are replacing the more expensive returnable type for shipments which are loaded and unloaded with the modern motor driven fork truck.

The lightweight of the corrugated

Figure 6 — Individual Carton, Matching Counter Display

Figure 8—A One-Ton Package of Locomotive Cylinder Sleeves is Packed and Secured at American Locomotive Co. for Safe Transit without Damage to the Parts. Fork Truck May Enter Base of this Package.

box as compared with the solid fiber makes it particularly attractive for air shipment and there is an increasing demand for a weatherproof corrugated container. Such a container is being made by producing a wet strength liner using urea or melamine resins, a sulfur impregnated .009 and a water resistant adhesive. These cases are being used for air shipment abroad to the armed forces as well as for other export business.

Paper Boxes

We now come to that portion of the industry which is somewhat older than the solid fiber and corrugated section, paper boxes. Paper boxes have been in use for over 150 years. The first were of the set up type. By this I mean a rigid, non-collapsible box delivered to the customer in the three dimensional shape ready for use. It is made from a rigid paperboard blank which can be overwrapped. Due to their being non-collapsible and consequently bulky, they are generally made by small concerns close to the consumer. They can be covered with paper, either plain or decorated, cloth, leather or any other flexible material so that there is little limit to the variety both in size and in the decorative possibilities. Typical of this type of box is the round hat box, incidentally one of the first made, the candy, cosmetic, and jewelry boxes. This portion of the industry consumes some 640,000 tons of paperboard per year.

Folding Boxes

Folding boxes, so-called because by their construction they can be shipped flat, and then set up at the point of use, represent by far the largest portion of the paper box industry. In 1950 about 2⅓ million tons of board were made for and consumed by the folding box industry. Unlike the shipping container, which by its very nature can be made with fairly large tolerances, the folding box is precision made. In most cases it must be set up, filled, and sealed on fast running automatic machinery. Depending on its end use these boxes must have strength if the product packed is heavy such as hardware, rigidity if the contents are breakable such as crackers, grease resistance if the material packed contains grease, and siftproof in the case of powders. This box can be made with windows of cellophane to give visibility to the contents and it can be so designed as to act as a dispenser for the contents as in the case of soap powder, waxed paper, paper napkins, etc.

Like many developments, today's folding box is the result of an accident. Robert Gair, the founder of Robert Gair Company, noticed that printing rule set too high made a clean cut in the paper being printed. This resulted in spoiled work but from it came the idea that by so setting these rules it would be possible to actually cut out the shape of a box, and by a slightly lower rule setting to produce a score along which the blank could be folded. Todays folding box is produced using this method for cutting and creasing. It has been adapted not only to the flat bed press but also the fast running, web

Figure 9—A One-Ton Package of 45M Cigarette Blanks Being Handled by a Fork Truck into Over-The-Road Trailer. Trailer is Loaded in Ten Minutes. Paper Expendable Pallets Allow Fork Truck Access

fed gravure press which will print several colors, cut and crease the board so that one machine delivers from a roll of board a printed blank ready to go on the gluing machine which glues up the side seam and delivers the folding box ready for shipment.

The folding box industry has kept pace with each development in the printing art and boxes are produced using letterpress, lithography and gravure printing. Much of the art work on boxes of this type is outstanding.

The folding box is made in all sizes from the large suit boxes, laundry boxes, etc., down to tiny pill boxes. The printing can range from a simple letterpress to a multi-color job suitable for jewelry and gift boxes. Board and foil can be combined to give very decorative effects. The materials packed in these boxes include such common materials as soap powders, cereals, foods such as crackers, and by the way, Uneeda Biscuits were the first commodity to be packaged in this manner, shoes, shirts, cigarettes, cosmetics and hundreds of other materials.

The folding box of today is made from paperboard produced on the multi-cylinder paper machine, with the principal raw material used being waste paper. It is a cylinder machine product because this machine is capable of producing a very wide variety of effects. It is conceivably possible to make a board on a machine with six or eight cylinders using a different shock on each cylinder. There are some limitations in that the stock on any individual cylinder cannot be too different in its paper making characteristics, such as freeness, from that on the next cylinder or there will be poor bonding, but a wide variety of stocks can be used. It is not general practice to use more than four different stocks in any one sheet but it is common to make up a sheet with a white top liner, a somewhat less white underliner, and a grey mixed paper filler and a smooth grey back liner of something like old newspaper. A white back liner can, of course, be used so that the board has the same color on both sides. For folding boxes this board should have good rigidity but should not be brittle. It must score without breaking or have bending quality. This is quite a different factor from the folding quality in paper in that the thickness of the board sets up large stresses in the scored portion of the sheet when it is bent at right angles to form a box.

Waste Paper

Before turning over the fiber to Mr. White who will talk about the problems of collecting waste paper, I would like to discuss briefly some of the problems

Figure 10—A Citrus Case at Sealing Machine

of its use in making board. During 1951 about 9 million tons of waste paper were collected in this country and the paperboard industry, including all the grades I have been talking about, is the largest consumer. Mr. White will tell you something about the grades which are collected, ranging from such high quality as white envelope cuttings, an excellent substitute for virgin bleached sulfite, down to mixed papers, which are just that, plus a very considerable amount of material that is not paper.

Theoretically even this lowest grade consists of better than 85 per cent of cellulose fiber. The balance may be clay from coatings or filling and one or two percent of what, for want of better name, I shall call dirt. There are three kinds of dirt: 1. Heavy, which includes sand, metal such as paper clips, glass, etc., 2. Light, including cellophane, rubber bands, plastics, wood, etc., and 3. Staining or spotting dirt, such as asphalt, wax, hot melt adhesives, etc.

If we had methods for removing these three types of dirt completely our problems would be much simpler. Your first thought probably will be why not sort the paper and eliminate these materials at the start. Again I will leave the answer to Mr. White with this comment. Sorting is costly. The lower grades such as mixed which make up over half of the sheet as we make it are low in cost. That is the reason we use them. Some of the dirt is hard to find. After all it is only a few percent of the total weight and the magnitude of the problem can be best shown by telling you that one of our mills consumes over 200 tons of this type of waste paper every twenty-four hours. Even in the form of bales 6 x 4 x 2½ feet in size, each bale weighing 1500 pounds we consume 16,000 cubic feet per day. That is a pile 200 feet long, 8 feet high and 10 feet wide. When the bale is broken and the paper bulked up for sorting, the space becomes many times as large. Consequently, we go directly from the bale to slush pulp.

There are several methods of doing

Figure 11—Typical Bag Making Machines

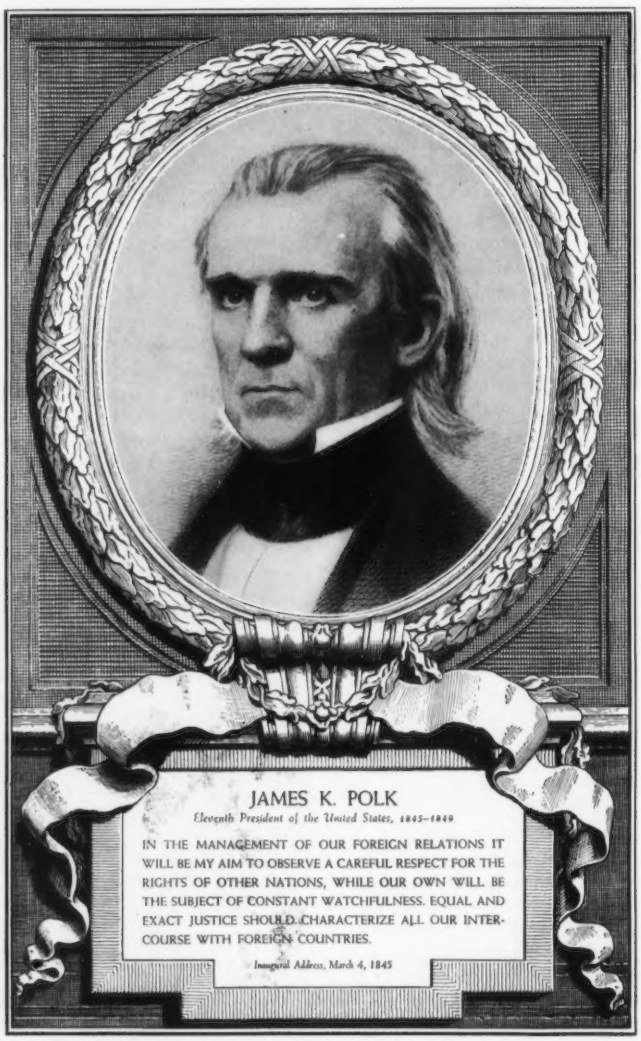
this, none of them perfect by any means. The one in most common use today is the hydrapulper which is a tub 10 to 20 feet in diameter and about 10 feet deep with a rotor in the bottom. The tub is partly filled with water and the waste paper and more water fed in. If the unit is of the continuous type it is equipped with perforated plates in the lower section, with holes from ¼ to 1 inch in diameter. The paper suspended in water as a slurry passes through these holes as soon as it is broken into pieces small enough to pass. Anything too large to pass these perforations is held back in the tub. Metal, glass, etc., fall to the bottom and into a junk well from which it can be removed. Bags and strings as well as wet strength paper are picked up on a cable dragging in the mass of partly pulped paper. These raggy materials will wrap around this chain forming a rope which can be continuously removed. Baling wire around the bale is cut and allowed to go into the hydrapulper to assist in forming this rope.

You can get some hot arguments regarding the extraction hole sizes that are best for this pulping operation. There are some definite limitations however. It is not practical to make the holes too small. If we do we get a de-watering effect and a greatly reduced capacity. Obviously, if the hole size is over ¼ inch in diameter, dirt of this size can and, I assure you does, pass. Also, undefibered paper passes.

This must be defibered before it can be remade into paper. If we do this with a refiner or Jordan we not only defiber the paper but we break up glass, and sand, cut up cellophane and rubber and reduce the size of asphalt or hot melt glues. The smaller we make the dirt, the harder it is to remove. Most systems in use today are compromises based on capacity, power consumption, and limitations of equipment available. Heavy materials are partially removed by gravity settling or with hydraulic centrifugal action. Light materials are screened out with coarse screens and in some mills asphalt, wax, etc., is dispersed by cooking continuously followed by a refining under pressure. This method, incidentally, does a very good job of dispersing asphalt so that the particles are too small to produce staining effects.

I very much doubt if you could find a board maker who is entirely satisfied with his removal of dirt. Technical men, in particular, are very critical of some of the machines and methods used. The industry as a whole is working for improvement but the progress seems slow mainly due to the costs involved. After all the end product must be cheap. If we add too much to the processing cost we lose the advantage of the low initial cost. If I were asked to prophesy my best guess would be that ten years hence mills will be equipped with much more extensive preliminary screening equipment, followed by hydraulic type centrifugal units, with the resulting stock continuously cooked at high density, and in all probability again passed through hydraulic centrifugals, just before going to the machine vats. This means a large capital investment but will in my estimation be forced by competition in quality.

I do not want to steal Mr. White's thunder, but as an introduction to his remarks I would like to leave this thought with you. In 1951, 9 million tons of waste paper were collected and used. If we translate this into forest with an annual growth of one-half cord per acre per year, and a yield of one ton per cord, the 9 million tons will represent forest growth per year on 180,000 acres or 28,000 square miles about the total area of the State of Maine.


JAMES K. POLK
Eleventh President of the United States, 1845–1849
IN THE MANAGEMENT OF OUR FOREIGN RELATIONS IT WILL BE MY AIM TO OBSERVE A CAREFUL RESPECT FOR THE RIGHTS OF OTHER NATIONS, WHILE OUR OWN WILL BE THE SUBJECT OF CONSTANT WATCHFULNESS. EQUAL AND EXACT JUSTICE SHOULD CHARACTERIZE ALL OUR INTERCOURSE WITH FOREIGN COUNTRIES.
Inaugural Address, March 4, 1845

HAVE FAITH IN AMERICAN PRINCIPLES

Draper Brothers Company
Canton, Massachusetts
WOOLEN MANUFACTURERS SINCE 1856

The DRAPER Fold

Sanitary Tissues

Charles M. Howell[1]

B.S. Swarthmore College, Cornell University, M.S. University of Maine. Employed by the Scott Paper Co. for twenty-six years as tour boss, chief engineer, engineering manager, general plant manager and member of the Board of Directors. Consultant to the paper industry for several years. Present position since 1951.

Introduction

I am going to start my talk today by making a little comparison between sanitary papers and writing papers. Some people speak of writing papers as being high quality papers. The inference is that if you are in the writing paper field you are in "quality" field and anybody else is "just making papers." I do not think that is true. There is quite a difference, of course, in the requirements of sanitary papers and writing papers because in writing papers one of the main requirements is permanency. Sanitary papers, for most part, are used once and thrown away. Therefore, permanency is of little consequence. There is great need for quality in sanitary papers, however, as there is in all kinds of paper.

What is quality anyway? It depends on what you are making. Every kind of paper and every kind of product requires quality standards. In my opinion, it is just as important to maintain the quality standards in one kind of paper as it is in another. Lack of quality standards is one of the things that held back the toilet paper industry in its infancy. From the very nature of the product, a lot of people took the attitude that quality in toilet paper was unimportant. Mr. Scott, at one of the early conventions, suggested advertising to make the public conscious of toilet papers. They laughed at him. Scott went ahead just the same, and, as you know, full speed advertising of these products in magazines are common today.

I do not believe, and I say this from actual experience, that there is any company making any product that emphases quality more than do a few manufacturers of toilet paper. Big businesses have been built on quality. Day and night the word is quality, quality, in any high grade toilet paper mill. I consider quality so important that when I get to a discussion of my charts, the discussion of the quality factors involved in sanitary papers will be the first points I will take up.

Sanitary papers should be made from suitable clean, soft pulps, in the cleanest of paper mills, by clean men in uniforms. Their sanitary facilities throughout the plant should be of the highest order in keeping with the kind of products being made. Quality should be a religion with the management and throughout the organization.

Before discussing sanitary papers in detail I would like to give a brief history of what has happened in the toilet tissue and towel industry during the past 30 years. I think that largely the same thing has taken place in the facial tissue field and the sanitary napkin field and it should drive home to you how the size and importance of the sanitary paper business has increased. I spent about a quarter of a century making tissue and towels and therefore, have actively participated in this growth. I have to make this personal, to a certain point, because I can tell history better that way.

When I entered the industry, in 1922, the newsprint machines running 1000 feet per minute were the fastest machines in the world. There were several in Canada and one or two in this country. I think the Great Northern Paper Company had one of them in this country. No other paper machines approached this speed at that time. The fastest tissue machine, and that was at the Scott Paper Company, was going about 450 feet per minute. Today, the fastest paper machines in the world are making facial tissue, toilet paper, and sanitary napkins. All of these papers are made at 2000 feet per minute or better. Not all the machines are running that fast, but there are machines making all of these papers while running at these speeds. The next fastest machines are used on kraft bag and newsprint and they run about 1800 feet per minute. Maybe some of them run a little faster than that. Scott, at Chester, Pennsylvania, has run 2500 feet per minute. One of the Scott machines at Fort Edward, New York, has run 2800 feet per minute in regular production on facial tissue. To the best of my knowledge, these are the fastest regular production speeds yet made by any paper machine. Kimberley-Clark is also close to these speeds on tissue.

Now the odd thing about these tissue machines is that they have speeded up without sacrifice of quality. The quality of tissue paper, and towel paper, has become superior on these high speed machines to what it was on the low speed machines. I do not have any samples to prove this statement, but I can assure you that it is dramatically true. The paper that was made on those low speed machines was much too hard, slick, and non-absorbent, and the appearance was not as good as it is today. These high speed machines make paper which has beautiful formation, is very soft and very absorbent, all of which qualities are necessary in sanitary tissue.

I would like to discuss this further just to show the growth of sanitary paper business. In 1922, Scott had two cylinder machines running about 250 feet per minute, two Harper machines running about 300 feet per minute and one top felt machine running about 450 feet per minute. One of their machines today would make as much production as the whole mill did then. The largest producer of toilet paper in those days was A.P.W. Products Company, Inc., in Albany, New York. They were the leaders in the toilet paper field. They had ten cylinder machines. One modern Fourdrinier machine will make more production than all those ten cylinder machines made in 1922.

The Scott Paper Co. business in 1922 was about three and one-half million dollars, and in 1951 it exceeded 120 million dollars. The toilet paper field was very small at that time. Sanitary napkins, towels, paper napkins, and all facial tissues were almost without exception either unheard of or just coming into use. I do not have any actual

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figures but I am quite sure that the sanitary paper field today constitutes a business that will amount to more than a quarter of a billion dollars a year, which is not small change. I looked up some figures in Lockwood's Directory. There are today about 70 mills making toilet paper, 44 making towels, and there are even 10 mills making toilet seat covers. Scott, by far, makes the most toilet paper and towels; and Kimberly-Clark, according to the last figures I have seen, makes the most of the sanitary napkins and facial tissues. I do not believe that Scott's or Kimberly-Clark's growth has been made at the expense of other mills. It has been mainly due to an increase in the total sanitary paper business.

When I first became a member of the Technical Association, TAPPI, I felt like a lost sheep because people looked down their noses at companies manufacturing toilet tissues. Today it is quite different because the sanitary paper business is a good sized business, quality minded, and running the fastest machines in the world. They have a very active committee in TAPPI in the tissue field. However, I do not feel that even today in the industry that it is fully realized how the tissue field has grown.

There is another angle to it that makes the sanitary paper field more important than the figures show. Figures quoted in books are usually given as so much tonnage production. It takes a great many feet of toilet paper to make a ton of paper, compared to heavier sheets. Another factor that should be mentioned is that the number of employees in the finishing operations is very high in the sanitation field. When I left Scott, for example, we had about 500 employees in the finishing department as compared to 1500 in the whole mill. The personnel involved in that industry, is therefore, quite large per ton of paper made as compared to most paper mills.

Sanitary Papers

What are sanitary papers? My answer to this question is shown in *Table I*. I have divided these papers into three classes. I intend to talk only about the first class which includes papers that come into direct personal contact with the human body purposes of cleanliness.

The second class is just getting started but the increase in the use of this type of paper has been accelerated by the development of wet strength. Lens tissue was developed during World War II for the Navy, mainly to wipe off the lenses of optical equipment on ships, etc., and wet strength overcame many of the problems connected with it. A direct off-shoot of that was a tissue developed for service stations for wiping automobile windows, etc. I do not think this is much of a business as yet. Kitchen towels were used before they had wet strength, but that product, in my opinion, is much improved and its field of usefulness greatly increased since the wet strength treatment.

TABLE I
SANITARY PAPERS

Class One
1. Toilet Papers
2. Towels
3. Facial Tissue
4. Sanitary Napkin
5. Luncheon Napkin
6. Seat Covers

Class Two
1. Lens Tissue
2. Car Wipes
3. Kitchen

Class Three
1. Kitchen Waxed Papers
2. Bread Wraps
3. Cake Wraps
4. Candy Wraps

The third class I do not intend to discuss at all. I consider as sanitary paper the kind used for wrapping food, lining for the kitchen shelves and any kind of paper that is used for protection of food. Wax paper, bread wrap, candy wrap, and other forms of wax papers are some of the papers in that field.

I am more familiar with the first classification of tissues, so that is the one I would like to discuss. In any case, this is, by far, the biggest in point of production of the three classes. The factors I am going to cover are, quality factors, raw materials, stock preparation, paper machine, finishing, technical control, and quality control, see *Table II*. There are other things, of course, but it is impossible to completely cover the sanitary paper field in a two hour period.

Quality Factors

The important qualities of sanitary papers are softness, absorbency, dry strength, wet strength, formation and general appearance, see *Table III*.

TABLE II
ITEMS DISCUSSED

1. Quality Factors
2. Raw Materials
3. Stuff Preparation
4. Paper Machines
5. Finishing
6. Technical Control
7. Quality Control
8. Conclusion

There are single ply and double ply toilet papers. In the single ply toilet paper, softness is the most important factor as determined by many consumer studies. Absorbency is also important. Dry strength is not very important in toilet paper. Any paper that will run over the finishing machine is amply strong. Wet strength is not desired in toilet paper because of the disposal problem. The opposite of wet strength is wanted here, namely something that disintegrades when it is wet. Formation and general appearance are quite necessary.

I will explain why finding out what the consumer wants is a very important factor in so far as quality control is concerned. One of the peculiarities of all these sanitary papers is that, for the most part, they are not sold to some company that is going to use them and can tell you what the quality should be. Instead they go directly to consumers and it is difficult to find out what 40 or 50 million people want in these different products. About the only way to do that is by making consumer surveys. An actual product is distributed to a certain number of consumers, used by them, and their opinions tabulated. Believe me, many preconceived ideas that you have, prove to be wrong when you find out what the consumer really wants. There used to be a lot of emphasis on formation before these surveys were made. We used to sacrifice some softness, to satisfy the idea of some inspector with regard to what the formation should be, until we found out the consumer rates softness of toilet paper above everything else.

In the double ply toilet papers, softness is even more important. Absorbency is also important, while the other things are about the same with the exception of formation. I do not think formation is quite as important as in single ply because two sheets together tend to cover up some of the defects. The consumer never sees the single ply but only the two of them together.

In facial tissues softness is again very important because women use it on their faces and they want it very soft. Absorbency, of course, is important. Dry strength and formation are not too important. Some wet strength is desirable because when they rub it on their faces if it does not have some

TABLE III

	IMPORTANT QUALITIES					
	SOFT	ABS.	DST.	WST.	FORM	G.A.
S. P. Toilet	1	2	3	0	2	2
D. P. Toilet	1+	2	3	0	3	2
Facial	1+	2	3	2	2	1
Sanitary Napkin	1	1+	4	0	0	0
Napkins	1	2	2	2	2	1
Towels	1	1	3	1	2	2

strength, it will disintegrate and leave fibers all over their skin. General appearance is very important in this product because I think women are very critical about a product like that. However, that is just a personal opinion.

In sanitary napkins, softness is very important, but for obvious reasons, absorbency is, by far, the most important factor. Quantity of absorbency is tested to determine the actual amount of liquid that each napkin will absorb. Dry strength, wet strength, formation, and general appearance are of little importance. They are enclosed in cloth and no one ever sees the paper itself.

In towels, softness is very important. For obvious reasons, I think absorbency is more important in towels than it is in toilet paper. Wet strength, particularly in a kitchen towel, is very important and particularly in folded towels because they are used largely in industry where they get quite rough treatment. They are good for wiping hands and grease because they hold together so well.

See *Table IV*. If the strength is improved, it tends to lessen absorbency and softness and to give better formation. If formation is improved, it tends to give more strength and less softness and absorbency. If the absorbency is improved, it gives less softness, strength, and formation. If the paper is made too soft, it is lacking in formation and strength. There is a limit to the extent that the softness can be improved in this way. On the other hand, if strength is emphasized too strongly, the paper has a tinny feeling and is not absorbent enough. It is a difficult problem in actual operation to secure the ideal of all these factors. It is not easy to get the best combination. Yet, the company which most nearly succeeds in this respect has an advantage with the consumer.

From the experience I have had, I believe that the quality factors in making sanitary papers are of primary importance. They have a direct bearing on all the other problems in operation. Everything in making sanitary paper is affected by the primary job in trying to make these paper of the quality desired by the consumer at a price they will pay.

Raw Material

How are we going to get all the qualities that the consumer wants? Soft papers and papers suited for all these different products are, fortunately easy to discuss because generally speaking all the papers mentioned in Class 1 have qualities and methods of production that are very similar.

Let us look at the chart of raw materials in *Table V*. All of these pulps are used today to some degree in all the sanitary products. The scarcity of pulps in recent years has been such that all paper mills have used pulps that they would not ordinarily have thought of using. Fortunately, because so many of the qualities of these papers are made on the paper machine they have been able to adapt themselves to most any kind of pulp with only slight losses in quality. Nevertheless, I believe if given their choice, the majority of these paper mills would prefer bleached sulfite.

TABLE IV

Improved Softness	Less Strength Less Formation More Absorbency
Improved Strength	Less Softness Less Absorbency More Formation
Improved Formation	More Strength Less Softness Less Absorbency
Improved Absorbency	More Softness Less Strength Less Formation

Rayon rejects are really a bleached sulfite, as you know, just cooked longer and a little differently to get a higher alpha cellulose content. There was a time in the early days, when we all thought it was necessary to have rayon rejects to get a good two-ply paper. Rayon rejects probably do make softer paper on the same machine than regular bleached sulfite, but they cost more and the difference in softness is not large.

Bleached soda pulp can be used to a certain extent. It is white but has a short fiber and only small percentage of it can be used from 10 to 15 or 20 percent. Bleached hardwood sulfate is better. This pulp has come into considerable prominence recently because pulp made from southern gum wood can be made almost as strong by the sulfate process as pulp from spruce by the sulfite process. That is particularly important in southern mills because there are a lot of gum woods in the South which can be used in the manufacture of bleached sulfate pulps, which are very good not only in tissue but in some other papers. I have heard that even some oak is being used with the gum.

Bleached sulfate pine is used more in towels. It is a pretty good quality for towel pulp although in the early days, I almost sweat blood trying to make it into a satisfactory quality for towels. I do not consider that it is as good as bleached sulfite made from spruce but it can be used to make a very satisfactory towel. The Scott towel today is much better than it was when I left the company and it contains considerable percentages of sulfate pine pulp. Perhaps they have overcome the difficulties by varying their cooking.

I once thought that sulfate pine could not be used for tissue at all because pine fibers are very thick and coarse. I remember making hand sheets of tissue out of bleached pine fiber. It was transparent and the fibers were so big, and thin walled, you could look right through the sheet. Yet, I heard just a few weeks ago of a mill that is even putting 30 percent bleached pine into facial tissue type of paper and two-ply toilet paper. It is wonderful what can be done in the face of necessity.

Ordinary spruce sulfate has been used for years. It is very good but it is scarce.

Unbleached sulfite can be used in tissues. There is nothing much wrong with that except the color. If a pure white is desired no unbleached sulfite can be used. It is widely used in semi-white toilet papers and towels. The towels made from unbleached sulfate are very strong and absorbent but dark brown in color and often have an odor when wet. The largest producer of unbleached sulfate towels is right here in New England, namely the Brown Co. They make a very good bleached towel, too.

Groundwood is also used and I would like to comment on that. There is nothing wrong with the use of groundwood, except its color, in a paper that is disposed of after it is used. Its use is very limited in white products. The development of the bleaching technique with peroxide bleaching, has, to a large extent, overcome that. I think, personally, that it is a great mistake that groundwood is not used more than it is for products which are used once and thrown away. Some qualities of the paper are actually im-

TABLE V
RAW MATERIALS

	S.P.T.	D.P.T.	FAC.	SAN. N.	NAP.	K.T.
B. Sulfite	1	1	1	1	1	1
Rayon Rej.	1—	1	1	2	2	3
B. Soda	3	2	2	2	3	4
B. H.W. Sulf.	2	2	2	2	3	4
B. Sulf. Pin	4	4	4	4	2	2
B. Sulfate	2	2	2	2	1	1
U.B. Sul-ite	2	2	2	2	2	2
U.B. Sul-ate	0	0	0	0	0	2
G. Wood	3	3	3	0	3	3

proved by the use of a fine groundwood. It is a fine fiber, it gives good formation, and good bulk. Of course, it only gives a reasonably white sheet but from the standpoint of conserving our resources, groundwood gives twice as much pulp as any chemical process except the semichemical process.

The only way to determine if there is any groundwood in tissue is by testing it with chemicals or microscopic examination. It is going to be thrown away anyway so why worry about having groundwood in it if the physical qualities are satisfactory. The only fault is the color factor, of course, and the fact that groundwood fades in light. It deteriorates quickly but not fast enough to be eliminated from a product that is going to be disposed of after the first use.

Stock Preparation

Some people say that paper is made in the beaters. I agree, with some limitations with that statement. I think it is more true in so-called fine papers than in tissues, which are beaten very little. Some years ago, when I was in charge of Technical Control at the Scott Paper Company, we spent about a year conducting experiments with all kinds of beaters. We tried jordans, Bauers, beaters, and all kinds of combinations. We engaged the services of an old papermaker from New England, who had been engaged as a consultant in the manufacture of fine papers, where beaters are the most important part of stock preparation and he suggested all kinds of changes to be made in the beater. Among other things, he had us enclose the beater roll. We enclosed the roll right in the tub and ran the stock through it continuously. He thought that this would do the trick. It made no noticeable difference. We found out, at least for tissue, that paper is not made in beaters altogether, though it is still an important factor. I mean that you can spoil any sheet of paper if you do not beat it for the requirements needed. With a given paper machine making toilet tissue, however, you cannot improve softness, at least, to any great extent by a change in beating. I remember one time when I really convinced myself that the beaters were not as important as some people had thought, at least, in making toilet papers. In those early days, we had skilled beater men who controlled beating, the same as in all mills of that time. The beating was specified as so many minutes with a light brush, so much time with a hard brush, and so on. The engineering department put motion recorder meters on the beaters. These worked through a cam and were so accurate that one line division on the chart was equal to a movement of 1/1000 of an inch setting on the knives of the beater roll. They measured quite accurately and, in my opinion, were the best controls ever put on beaters. Without mentioning anything about it, I started to check on the beater men, before we started to use the recording meters in actual operation. I found out that on the light brush the roll should be set with the knife just touching the bed plate. This could be checked by putting one end of a stick down on the extension of the bed plate and putting the other end up to the ear. It is easy to tell by listening whether the knife is hitting the bed plate or not. I also found that some of these four beater men had the knives actually brushing the stock and some of them had the knives one-eighth of an inch away from the bed plate.

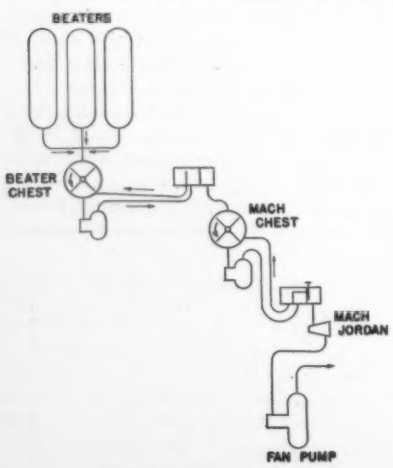

Figure 1—Beater System

We came to the conclusion that if the skilled beatermen varied the settings of the roll for a light brush to such an extent, we should get a gain in uniformity of prepared stock if we used the meters and specified the setting of the rolls as follows: (1) so much time with the pen drawing the line at one line on the chart for a light brush and, (2) so much time on another line for a heavy brush.

This was done. The charts were carefully collected and changed daily. A technical control man checked the zero setting of the beater rolls once a week, at the point where the knives just touched the bed plate. This method of control was continued until the beaters were replaced with wide knife jordans. We were very pleased with the results.

Personally, I am glad that we found out that most of the paper making is done on the paper machine, in the case of toilet paper, towels, and similar papers that are highly creped.

As I have just indicated, the gains that have been made by varying the beating and that sort of thing have been minute. You could hardly detect the improvements and changes brought about by different methods of beating. When we began to work with the paper machine and started to crepe, using a crepe drier and putting more crepe in as well as to calender differently, the improvements that were made were sensational. The result is that there have been great improvements made in the toilet paper and towel paper field in the last twenty years. Some people may well differ with me, but I think I can prove that there has been more progress made in the manufacture of tissue, as regards speed, quality, and amount of production, than in the manufacture of any other type of paper. I suspect that one of the reasons that the rag paper machine has not made too much prog-

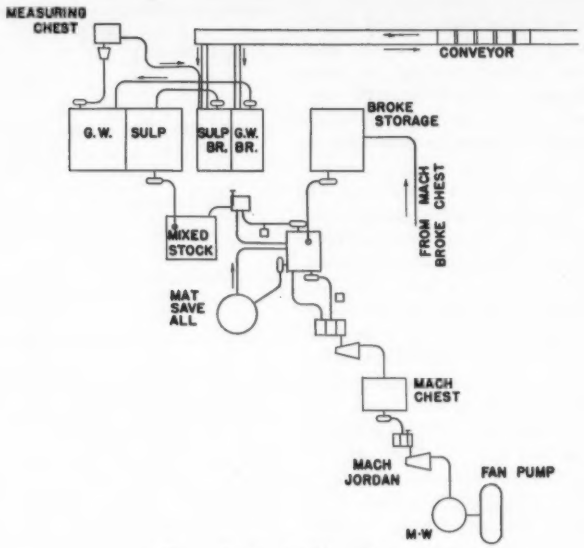

Figure 2—Stock Mixing System

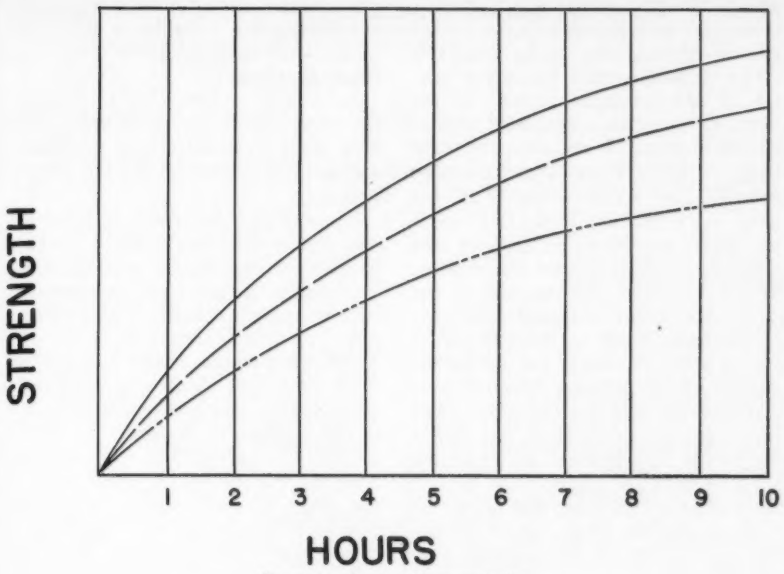

Figure 3—Beater Characteristics

ress is because so much of the work is done in the beater. A rag paper mill today looks just the same to me as it did in 1922. I can see but little change in the paper machines in rag mills. I like to see progress, improvements, and changes and so I am glad that I happened to become affiliated with a progressive tissue manufacturer back in 1922.

Originally, as I stated, we used beaters. Any number of different combinations of beaters can be used. I have only picked one as an example which is shown in *Figure 1.* We had about three Hollander beaters for each paper machine. We dumped into a beater chest, pumped it from there to the stock box, that had a gate, and it overflowed back to the chest so that the men could maintain the level in the machine chest by manipulation of that gate. If the paper machine shut down, the operator had to shut the gate entirely. If the machine slowed down, he had to close the gate a little. If the machine speeded up, he had to open it a little. That is hand regulation. The only thing he had to help him was a level gauge in the chest. There was a pump at the machine chest to pump the stock to a gate, called the machine tender's gate, ahead of the machine jordan. By manipulation of this gate, the machine tender maintained the weight of the paper on the machine. If the sheet got heavy, he shut that off a little. If it got light, he opened it to let in a little more stock. A slight speeding up or slowing down of the machine was also a means of quick adjustment but, by and large, he opened or closed this gate to regulate the weight of the sheet. The stock was sent down to the suction of the fan pump which pumped the stock and water to the machine.

I want to explain the function of the fan pump. First, there is a mixing well where the water drains from the Fourdrinier. The water used to form the sheet runs into a pan where it is collected and sent back into this mixing well. It is then pumped to the head-box and out onto the wire. The water thus circulates and the stock is filtered out on the traveling wire. That is how you form the sheet. This pump is called a fan pump, head-box pump, or circulating pump. Common practice is to put fresh stock in at the suction of this pump but Scott did it in the mixing well. Theoretically, I believe it is a little better in the mixing well but the others seem to run just as well as far as I can see.

It is very likely that with fine papers which require that they be well beaten, better results are realized by use of beaters. As far as sanitary papers go, however, the beating is so very little that equally good results are secured with jordans. We have proven definitely to our satisfaction that equally good results are secured with jordans, and practically all mills making that kind of paper have done the same.

The system shown in *Figure 2* is quite elaborate. This system served two paper machines on one grade of tissue and a duplicate system served four machines on another tissue, so they handled a lot of stock. The conveyor at the top of the chart brought the pulp in from the wharf. The whole furnish was made up on this conveyor and consisted of some groundwood and sulfite. We treated the groundwood separately, as anybody that buys baled groundwood probably should do, to avoid trouble with dry groundwood stock specks. Even if it is 50 per cent dry, it will get air dry on the outside and it is then hard to defiber completely. If dry groundwood is put in with the sulfite there may be little specks of groundwood in the paper. In order to avoid those, the groundwood should be treated separately. The defibered groundwood treated was so small that it was possible to get quite a drastic treatment. The jordaned groundwood was then stored in a measuring chest.

We had a big box on the top of the chest and we measured the amount of groundwood needed to furnish one breaker load of sulfite. When we pumped the sulfite, we put a measured amount of pre-treated groundwood into the sulfite breaker. The breaker tank mixed it thoroughly. We tried quite a number of different systems and we got the best control with the least trouble with this one.

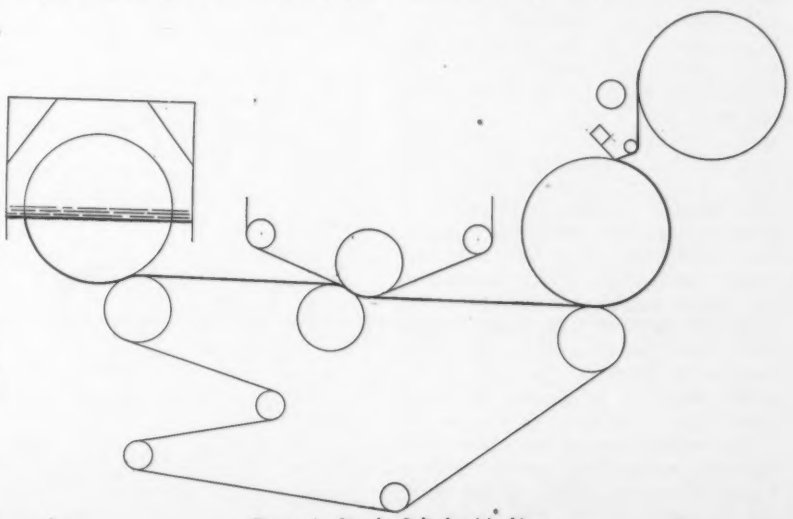

Figure 4—Simple Cylinder Machine

Each machine had two breaker tanks. One was on the dry end defibering dry broke coming back from the finishing department and any broke that was made at the calender or the reel. There was another one right underneath the Yankee dryer. Whenever we started up the paper machine, a run of wet broke was made for five or ten minutes while the machine was being adjusted and before the sheet was sent over the dryers. This dropped automatically into a little broke breaker tank. There was also a big broke storage chest. You may have seen mills where broke is stored everywhere. That is something you never see today at mills equipped as just described. The broke is disposed of as fast as it is made. It is not left laying around on the floor. This is easier to do, of course, in a mill making just one brand on the machine while in others it is not so easy because of short runs on different brands with the broke from each to be disposed of. It is difficult in such mills.

When broke is pumped from the broke storage chest, the broke is of the same furnish as is being furnished in the regular breakers. Therefore, the beaterman was permitted to admit it as fast as needed into the prepared stock chest. He pumped the broke up to the control gate and put in the amount of broke that was necessary. He would ordinarily not have to change the gate often. The Technical Control Department checked him closely on any changes.

Then, instead of having beaters in the beater room we had jordans. These had thick knives so as not to cut the stock. They were three-eighths to five-eighths of an inch in width.

We also used a mat covered save-all. This was a revolving cylinder covered with fine mesh wire. It was the same machine that you have seen used as thickeners in a pulp mill. In order to get more of the fine stock out, the fresh stock was pumped from the beater chest to the suction of the save-all pump and a thick mat of fresh stock, one-fourth to three-eighths of an inch thick, ran out onto the save-all wire. This acts about the same as a filter paper in the laboratory only it is a continuous, wet stock, filter paper. The stock then went back into the beater chest where it was pumped to the paper machine stock chest. In other words, use was made of the fresh stock on its way to the paper machine to catch the fines out of the white water. It is possible to obtain good, clear white water in this way.

The original save-all ran white water alone on a revolving cylinder with a Fourdrinier wire. Some of the stock can be taken out by this means but most of the fine stock will go through. A save-all with a mat has the advantage of catching most of the fines, too.

The machine tender was given control of the machine jordan. If the sheet got too hard he likely backed off the jordan. If the strength went down, he might try to put the jordan on a little harder providing it did not make the paper too hard. If it made the paper too hard, he had to find some other way to get the strength up. He might make adjustments of the water. He might add more water to the head-box pump to form the sheet a little better or maybe put a lot more presure on the presses, which has an effect on the strength. There are many different ways of doing it. So far as the jordan is concerned, he might put it up to increase strength or back it off to improve softness. He might put it up to improve formation or back it off. That is part of the machine tender's control.

An examination of *Figure 3* will aid in showing my own explanation of why it was that we could not find much difference in the type of beating used. If you are beating a long while, as in the case of writing paper, for instance, and happen to follow two different curves in two separate instances, by the time you get it up to the beating end point you will have a wide difference between these curves. But operating on tissue and towel paper, even with two different curves of preparing the stock, the beating has not progressed far enough along the curves to make very much difference. This explained to my satisfaction why, on toilet paper and towels, we were not able to change the qualities of our paper appreciably by different methods of beating. I think we did not go far enough along the beating curves to bring out the differences that undoubtedly would result in various methods of beating if the ultimate strength was developed. We went but a little way towards the optimum point of beating.

Paper Machines

As I said before, this is certainly the point where the most gains have been made in qualities and production and sanitary papers in the last twenty years.

The cylinder machine, see *Figure 4*, was widely used originally. I imagine, because it was simple and relatively inexpensive to put in as compared to the Fourdrinier. Instead of having a long Fourdrinier section there was just a cylinder mould covered with fine mesh wire. The white water, and stock and water mixture, came in and drained through the cylinder which turned and carried the sheet around. The felt picked up the sheet, carried the sheet through one press and deposited it on a small dryer from which it was removed by creping. Some papers were not creped. Then it dropped down into a small dryer. It is a very simple, inexpensive machine. However, do not think that because a cylinder machine is simple it is easy to operate. It is much harder trying to get controlled uniform formation on a cylinder machine than it ever was on a Fourdrinier. They are very tricky machines. I do not know why. I did not learn very much about them because they did not keep them around very long. I do remember we had a lot of trouble getting uniform quality before we replaced them with Fourdriniers.

Cylinder machines have the objection, too, of making a paper with very much directional strength in the machine direction. When forming the paper the cylinder turns around and drags the fibers through the water and tends to line them parallel to the machine direction so that the paper is very strong in machine direction and very weak in cross direction. A paper

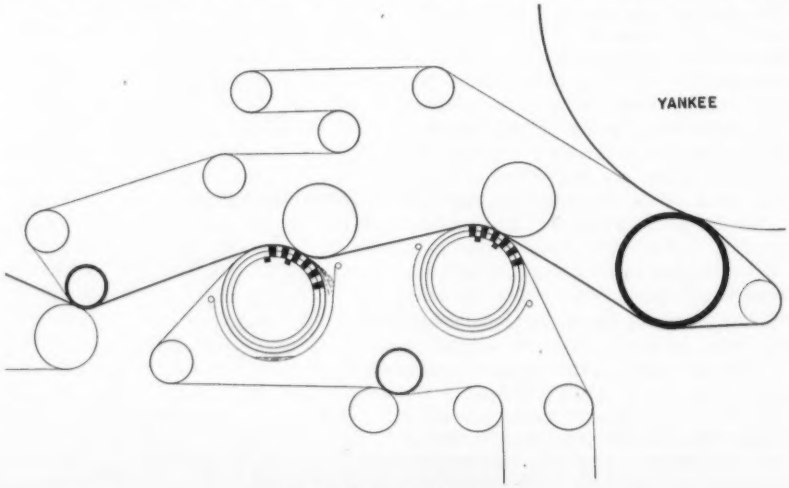

Figure 7—Tissue Machine

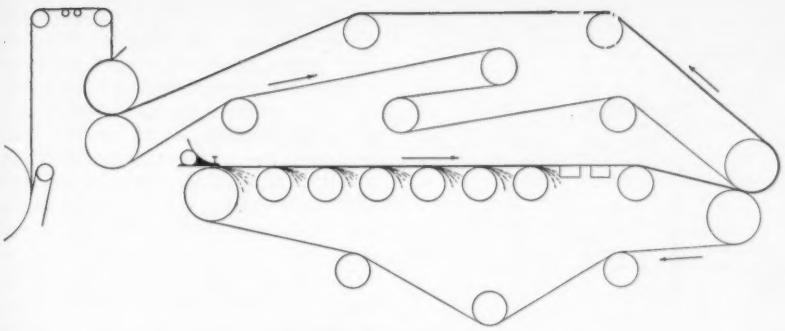

Figure 5—Harper Machine

that is cylinder made will tear in a straight line right down the middle. If it has been made on a Fourdrinier it will usually tear in any direction. Most mills like to get as near a "square sheet" as possible. That is a sheet with the strength in cross direction the same as it is in machine direction. Actually, I think practically all papers are a little stronger in the machine direction than in the cross direction. I doubt if anyone is making a 100 percent square sheet.

Another type of machine shown in *Figure 5* is the Harper machine which was widely used and still is used to some extent, although less and less all the time. It is like a Fourdrinier only it travels in the opposite direction. On the Harper, the slice and the head-box are on the dryer end of the wire and the wire runs away from the driers. There have been changes but this is the type of Harper used at the Scott Paper Company when I went there. The main advantage of the Harper is that the sheet is supported all the way through on a felt. I understand that some cigarette papers are still made on it, and I know some toilet papers are, but, like the cylinder machine, it is becoming obsolete for use in tissue paper manufacture.

Figure 6 shows an open Fourdrinier. This is like a newsprint machine only with a shorter wire and less table rolls. The sheet goes over table roll forming boards, deflectors and suction boxes and comes off a suction couch, then goes over to a wet felt, onto the presses, and then it is dried. This is the type of Fourdrinier largely used on towels today.

When they first started to make tissue papers on Fourdriniers the only change was the replacement of the suction couch. They put on what was called the Edwards attachment. That was a section of top felt that merely picked up the sheet off the wire at the couch, carried it through and deposited it on the first press. In other words, on the first top felt machine, the top felt did not go all the way through to the creping dryer as it does now. A light paper will not run well. It will break too much. We have tried to make lightweight paper on a Fourdrinier without a topfelt. About the lightest weight possible is fourteen and one-half pounds and it was far too heavy, and too hard, for toilet paper. The paper was thin and would only run about 300 feet per minute. This was done in 1922.

The top felt machine which is the type used now is similar to *Figure 7*. You can run it at almost any speed. The paper is picked up off the wire by the top felt, carried through, and deposited on the Yankee dryer. The lightweight sheet of paper is supported all the way through until after it is creped. There is a doctor on the under side of the Yankee that crepes the sheet.

This machine has the advantage of being able to run at very high speeds. In spite of the fact that we tried years ago to do away with the top felt, that was before we had really learned very much about it and in my opinion, it is the most efficient type of paper machine on lightweight papers that has yet been developed. It is a very efficient combination because the water does not have to go through the top felt and permits the use of a very heavy, closely woven felt. As a matter of fact it has to be closely woven in order to pick up the sheet. At the same time, a soft, open woven, bottom felt can be used. The result is that the closely woven top felt seals off the suction roll and gives a high vacuum with relatively low power consumption by the pump. The soft open wet felt gives very good water removal, because it is very light, soft, and open and the higher vacuum obtained by using the heavy top felt results in a drier sheet at higher speeds than on any open machines. One of the reasons why the tissue machines run at such high speeds today is due largely to this efficient water removal arrangement.

Formation was one of the first factors that had to be improved on the paper machine in order to improve the speed of the machine and the quality of the paper. The manufacture of paper at high speeds had to be investigated and developed. Then better presses were needed so two more suction presses were installed.

When we first tried to increase speeds on the paper machines for tissue, the top felt arrangement was similar to the modern one but we kept the type of Fourdrinier which is ideal for making paper of about the weight of newsprint and kraft bags. Often Fourdriniers of this type will run 1800 feet per minute on newsprint and kraft. The details have been changed but the Van de Carr type of slice, dandy rolls, forming boards, and so on are still used. The thing that is wrong with this Fourdrinier for lightweight papers is that the solid rolls take out too much water. Instead of having just one forming board, on tissue we tried additional ones just to hold the water in the sheet. With the solid rolls, every time there is water underneath the wire, it has no place to go because it cannot go into the solid roll, so it goes into the sheet and marks it, thus spoil-

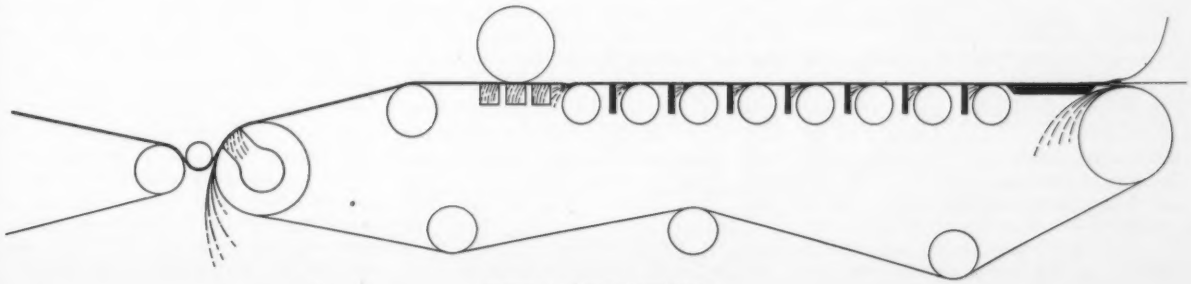

Figure 6—Open Fourdrinier

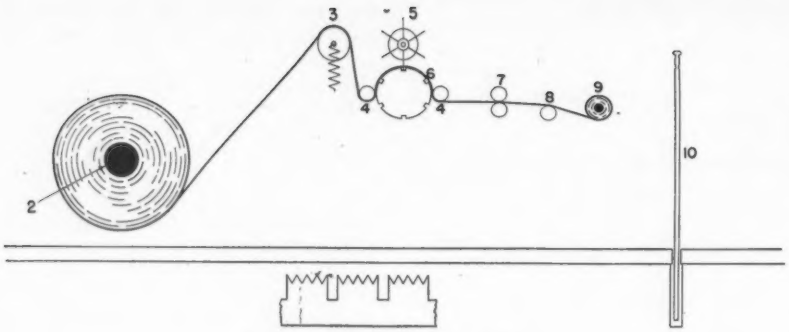

Figure 8—Toilet Paper Roll Machine

ing the formation. This is particularly noticeable on tissue.

I do not know where they got the idea but two smart fellows at Kimberley-Clark began to work on a different principle. Instead of trying to overcome the deficiencies on a lightweight paper on an ordinary type of Fourdrinier by trying to hold the water in, they conceived the idea of developing a Fourdrinier that would take advantage of the lightweight paper and get the water out of the sheet almost instantly. They came through with the pressure inlet. With that they ran the slice out over the wire. They had to run that with a theoretical head behind the inlet. In other words, they had to run the head to a height to get the velocity of water equal to the velocity of the wire. It took a lot of water. They practically formed a sheet right there on four inches of wire and at a very high speed. They are still running that way at Kimberley-Clark as far as I know.

Instead of using the solid roll that they started with, they got so much of the water out under the inlet due to pressure that they put in a dandy roll which removed very little water. These are of very open construction and water passes through them with little disturbance to the formation of the sheet. Instead of the water coming up through the wire and spoiling the sheet as it did with the solid roll, the water passes through the dandy rolls without disturbing the sheet and falls into the pan. So they were able to run at a much higher speed and with better quality of formation. The formation is almost perfect.

It does have one drawback. To some extent it has the same effect on the directional strength as do the cylinder machines. There appears to be some drag effect. At any rate, there is more directional strength developed on this type of machine than with a standard Voith or Van de Carr type of slice. This, however, is not all loss because on the paper machine the paper will be stiffer in the cross direction than it is in the machine direction. The crepe to some extent acts like corrugated sheet metal. I mean there is some of that effect, not much, but some. Of course, the fact that the cross directional strength is a little weaker compensates somewhat for the stiffening in the cross direction and so makes the paper feel softer.

As soon as we heard about the pressure inlet we put it on our machines with their permission. We had been running at 1000 feet per minute before that which was much faster than any other at the time but with this innovation we ran as high as 1450 feet per minute, or a little more, with an improvement in quality and softness.

A still further development on recent tissue machines has been the addition of the suction breast roll to the pressure inlet. This suction roll is constructed something like a dandy roll. Not only is the water forced through the sheet by pressure but the pressure differential is increased by creating a vacuum underneath the roll. That machine has been run experimentally at 3800 feet per minute.

Speed of tissue machines is no longer limited by formation. The limiting factors have moved up to the dryers and the dry end of the machine.

We found out that big gains in toilet paper, towels, and all of these sanitary papers were made by Yankee dryers. Originally when I went to Scott they creped the paper when it was cold. At that time you could get about 30 to 33 percent bone dry stock. At this moisture content the sheet would only hold a little crepe. You could get only a little softening effect. When we put in the Yankee dryers, we found that the papers would crepe all the way from 50 percent to 95 percent bone dry. These are drynesses at which facial tissue, toilet paper, sanitary napkins, two-ply toilet paper, and others are creped today. That is done with Yankee dryers. Creping dryer increased the softness a great deal. When I left the tissue field we were creping at about 55 percent bone dry on the single ply sheet. In creping we found out that the dryness at which the creping is done is one of the main factors in softness control. The effect on the softness is multiplied many times by creping it dry rather than creping it wet. Of course, another factor in creping is the amount of crepe left in the sheet. Other things being equal, if more crepe is left in, it will be softer.

When we first made Waldorf we were not calendering it all and calendering Scott tissue only very lightly. When a creped paper comes off the dryers it is pretty rough but as it comes over the dryer and through calender rolls the surface is improved. Calendering does not actually improve the pliability but it greatly improves the surface feel. Stiffness tests do not show much of any improvement after it has gone over the calender but it improves the surface feel so much that the paper feels infinitely softer than it did before it was calendered. Creping, therefore, improves the pliability, and calendering improves the surface feel, the combination giving a sheet that feels very soft to the human touch.

That is enough about the paper machine. The gains made there were brought about by improving the formation, the press section, the creping, and the calendering. This is where the big gains in quality, production, and reduced costs were made on all these sanitary papers, right on the paper machine. If there are any mechanical engineers here today, note that this is practically all mechanical. I say this to indicate that there is a field for mechanical engineers as well as for chemical engineers in the paper industry. There is plenty of room for both.

Finishing

I have not time to go very far into finishing but I can show you, at least, a cross section of a typical finishing machine in *Figure 8*. The jumbo roll, number 1, has a big metal core. Although it is not shown here, there is a brake on this core that puts a tension on the sheet. The brake is under the control of the operator and it is also automatic. Whatever tension the operator puts on the sheet by the brake is maintained automatically but he can increase the tension if he so desires. The wide sheet in jumbo rolls is cut into narrow sheets of toilet paper by the knives shown in 7. It takes about four of these machines running 24 hours a day, with down time for the operator's meals, to finish the production of one paper machine. At least, that is the way it was when I left.

The paper goes over a spring roll,

3, and then under two little rolls, 4, called feed rolls. These are spirally wrapped with new pickup felt. We found that top felt works better than anything else we tried. When they go through, the wool seems to grip the paper just about right and has enough flexibility and surface attraction to the paper to give very good results. There are six slots around the surface of the drum, 6. The severing head, 5, is synchronized with the drum. As the paper goes around the drum, the saw toothed severing knives go down through the paper into the slots and the paper is severed with what we call perforations. The distance between those slots is equal to the length of the sheet of toilet paper, four and one-half or five inches.

After the paper is cut to width it goes through the slitter knives which cut the paper into strips four and one-half inches wide. These knives are on shafts and set four and one-half inches apart. It is a shear cut and it is quite a trick to keep those knivse sharpened and working right. A special maintenance department takes care of just the maintenance on the finishing department, and the men in that department are highly skilled. One man does all the sharpening of the knives and that has to be done just so. They are run at very high speeds and are started and stopped frequently, so the service is severe.

There have been a lot of attempts to make continuous machines, and some partially continuous machines have been developed. One machine made by a company in the middle west merely slows down to change from run to run. We investigated these but we were running so fast that we got better production than was secured with the continuous machines.

Number 9 is a winder bar with little cores on the inside of the roll of toilet paper that had to be put there by hand by the machine operator and his helper. The bar on which the cores were put were so long they had to insert about one-third of it into a hole in the floor so he could reach the top of it. He would put a few cores on before he put it into the slot and finished with the remaining cores. The helper assisted him in putting them on.

A number of years ago, we developed a machine to put those tubes on the bar automatically. We did not save much money because we had the cost of the extra machine and we had to have girls up in the loft to sort and arrange these tubes on a little conveyor that brought the tubes down and pushed them on to the bar automatically. That was quite a job to do for eight hours a day before these machines were developed so it was a big

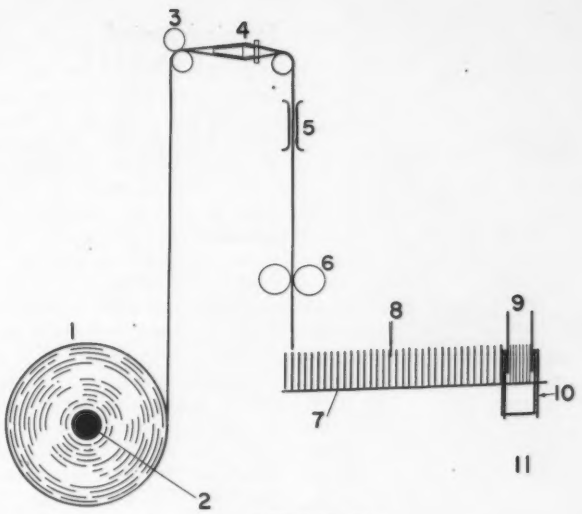

Figure 9—Roll Machine

victory when the operation came in because the work of the runner was much easier and we could run faster.

Number 8 is called a spreader bar. The winder bar, 9, fits into another little device which is called a winder clutch. Many years were spent in developing this because it requires a mighty good clutch to prevent the sheet from breaking when starting and stopping at high speeds. The mechanical engineers made quite an improvement by installing the automatic brake tension control. Originally this brake was controlled by hand and when the jumbo rolls were big and there was a large radius and a lot of weight, the tension required on the sheet was quite different than it was as the roll got smaller. So the brake had to be adjusted manually several times on each jumbo roll. Also when the machine started up the brake was still on. It was hard enough to start that machine without having to overcome the effect of the brake too. So we got the idea of installing an automatic brake. The spring roll controls the tension in the sheet by automatically adjusting the brake. When starting up, the tension of the sheet will pull that roll down and it relieves the brake automatically. So, all that is necessary to start the roll is to pull the weight of the roll. By the same token, as the roll gets smaller the running tension of the sheet is maintained constant because the tension on the spring roll adjusts the brake automatically to a constant tension on the sheet. This is one of the biggest single improvements made on those roll machines. They speeded up the machine and improved the quality of operation.

The main quality factors that we have problems with on the roll machine are getting good perforations and good cutting. If the knives are not

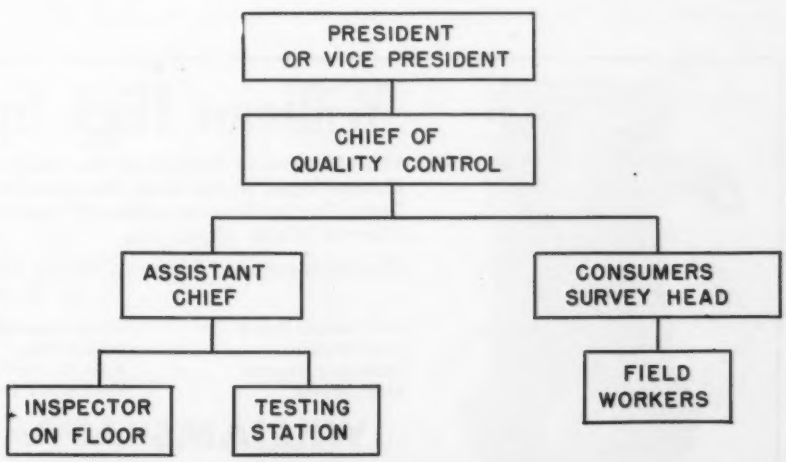

Figure 10—Organization Chart

sharp, they cause a ragged cut and poor appearance in the finished roll which will cause it to be thrown out because of being below quality standard. We had a problem of keeping the knives sharp.

Perforations is one of the problems we had, too. Toilet tissue is a creped sheet with a lot of starch. If the severing knives are just a bit dull, they will push the paper down in the slots instead of cutting all the way through the sheet and such uncut perforations will not part easily. We did several things to overcome that. The first thing we did was to cover the drum with a very thin and accurately made cloth. Pool table cloth was the best of anything we tried and it helped a lot. Inserts were placed in the slots of the perforating drum so that the sheet was supported under each section of unsevered paper. This kept the severing knives from pushing the paper down into the slots.

On folded towel machines, see *Figure 9*, the paper is slit and run through a former, 4, commonly called a "boat former." It requires a perfect adjustment to keep it on fold. This is used on all kinds of paper that requires folding. I have seen it used on a newsprinting machine. They call it a boat former because it is shaped like a boat. An additional fold is necessary. The towel paper is folded once, then it is folded into a "C" fold at 5 and then it is cut off at 6. Rotary knives are used for cutting. The towels are cut, then they come down on the conveyor, 7, and over and under a plunger, 9. After 150 towels are collected and compressed, the plunger pushes the towels into a carton that the operator has placed on forms under the plunger. The operator then places the loaded carton into a case.

Technical Control

Technical control is very important in any mill and, I think, it is important in this type of an operation because to get quality at high speeds requires very exact control. With light paper running so fast, one has little time to correct mistakes. Too many mistakes would result in excessive broke, loss of production, and high costs. The thing to do is to set up real technical control and try to avoid these mistakes so that the machine can be run at high speeds with little interruption or variation in quality. I have seen a tissue machine run as much as 72 hours without a break or a shutdown or any losses whatsoever, at a speed of 1400 feet per minute on the Yankee. The technical men have played a tremendous part in this. Several hours could be devoted to a discussion of *technical control* alone. The main functions of technical control are shown in *Table VI*.

TABLE VI

TECHNICAL CONTROL

1. Tests Pulp, Coal, Oil, other raw material.
2. Specifies and writes furnishes
4. Performs routine tests on driers tempt., moist.
4. Performs routine tests on driers tempt. moist.
5. Performs routine tests moisture after presses.
6. Checks stock losses daily.
7. Checks percent crepe daily.
8. Collects, studies and files meter charts.
9. Investigate unusual variations.
10. Measurement and record crowns, density.
11. Tests in finishing; glue, paste, wrappers, tube board cases, etc.
12. Locate causes of quality variation.
13. Special tests as called for

Quality Control

There is only one of two places that the head of the quality department should report and that is to either the president or the vice president, as shown in the organization chart in *Figure 10*. He should be entirely independent of the operators. It is a tough job and an unpopular one. It is, however, one of the most important jobs and he cannot do it justice unless he reports to the top management of the business.

He has to be very trustworthy and his character must be above reproach. He must be tactful and at the same time, a very strong willed person. He must have good judgment, and not be affected by the people getting mad at him or let his judgment be swayed. He should have two departments with one chief to look after routine quality control in the paper mill and other operations, and another chief to make the consumer surveys that determine what the quality should be. Then he has the job of selling the management on some of the survey findings when certain changes should be made on the paper in order to satisfy consumer demand. He needs a very good man on this survey work. I cannot emphasize too much the importance of this type of work.

Conclusion

I am afraid to have talked too long and yet I feel I have not done justice to the subject, particularly the later charts. I had to hurry on these in order to finish in the time allotted.

I hope I have been able to give you some idea of the variety of the problems that will confront you if you enter the sanitary paper field. I can assure you if you do that you will have plenty of hard, interesting problems to solve and that there will be very few dull moments. Thank you for your interest as shown by your close attention.

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Instrument Applications in Pulp and Paper Mills

Edward F. Thode

Graduate of Massachusetts Institute of Technology, S.B., 1942, Sc.D., 1947. Three years as Chemical Engineer in the Mechanical Rubber Goods Industry. On staff of University of Maine since 1947, now Associate Professor of Chemical Engineering. Active in research in Pulp and Paper field, partciularly with regard to surface properties of fibers and furnish constituents.

Introduction

From the fanfare of publicity regarding instrumentation that one may observe in the lay press as well as in the technical magazines, one may conclude that the elements of a fad of "instrumentation" are present. Such an "instruments fad" may have the same effect on the technical man in the mill as the "plastics fad" of recent years had on the housewife.

In some instances, plastic products purchased with the intent of making the work of the housewife lighter had the opposite effect as a result of overenthusiasm on the part of the buyer or seller, because the products were used for purposes for which they were entirely unsuited. The disillusionment that followed often resulted in a rejection of more suitable products that came later.

So it may be with instruments. Instruments perform many labor-saving functions and, if judiciously employed, contribute to a greater efficiency of production. But, instruments do not run mills. Men run mills, and men run the instruments. The mill operator or supervisor who is not informed on instrument potentialities may attempt to have his instruments perform functions for which they are not suited, to his sorrow. On the other hand, the mill man who is fully informed of their limitations will stand to gain much in the saving of money, materials, and labor through judicious application of these devices.

As an example of this, I am reminded of the case of an instrument designed to indicate and record continuously a certain property of the finished sheet as it emerges from the dry end. I visited one mill that had nothing good to say about the instrument at all. The machine tender could never maintain a constant value no matter what he did. The calibration was tricky, and needed frequent checks. The device was no good mechanically. It was always out of repair!

A few months later, I visited another mill that had one of these instruments on every machine. "How do you like them?" I asked the Superintendent.

"Wonderful," he replied. "We wonder what we did before they were installed!"

There were several important differences in the mode of application in these mills: In the first place, Mill #1 had attached their instrument case right to the frame of the paper machine. Mill #2 had mounted their instruments on concrete posts well away from the machines. While modern electronic devices are incredibly rugged, there is a limit to what many of them may be able to stand in the way of vibration and similar mechanical abuse. Mill #2 thus had by far and away less maintenance troubles than Mill #1.

The second difference was that Mill #2 did not ask the machine tenders to maintain a *constant* instrument reading. It was manifestly impossible in this case so to do. Instead, limits were set up, with flashing lights arranged to show the machine tender from anywhere on the floor whether he was over, or under, or within the specified range.

Lastly, Mill #2 licked the problem of calibration by studying the instrument performance over long runs and amassing a great deal of data. Because of the many variables involved it was impracticable to use the instrument on short runs of specialty papers, so it just was not used.

Thus you see the necessity for realizing the limitations of an instrument in order to get the most out of it.

Basic Circuits

We may well leave the intricacies of electronic instruments to the appropriate specialists, but it is possible to intelligently discuss most modern instruments by referring to two very common and very simple circuits, modifications of which are needed in virtually all electric measuring devices that go beyond a simple galvanometer. These two circuits are the potentiometer circuit shown in *Figure 1* and the Wheatstone bridge circuit given in *Figure 2*.

In *Figure 1*, a simplified potentiometer circuit such as might be used in thermoelectric measurements is shown. E is a battery capable of supplying a greater voltage than is to be measured, K is a variable resistor used to reduce the e.m.f. output of the battery, R_1, S, and R_2 together comprise the potential divider across which the known e.m.f. is applied, while X is the source of unknown e.m.f. The galvanometer, G, and the slide wire contactor, C, complete the circuit. The standardizing circuit needed to adjust K

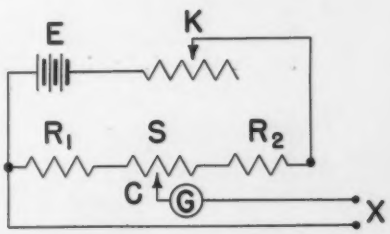


Figure 1—Potentiometer Circuit

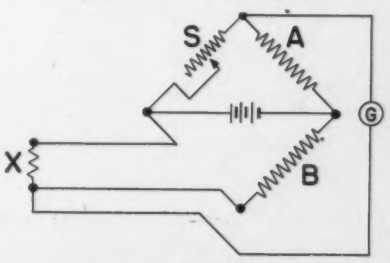
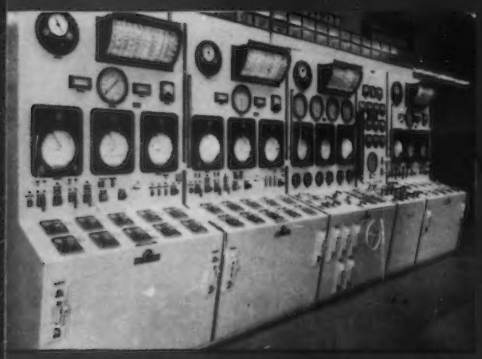
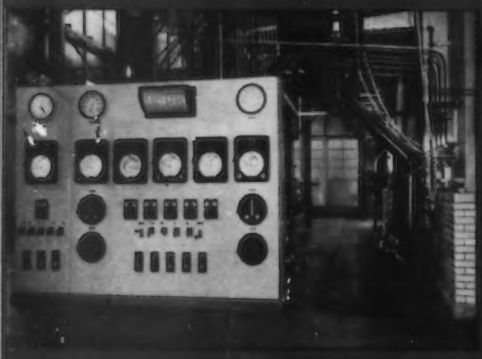


Figure 2—Wheatstone Bridge Circuit





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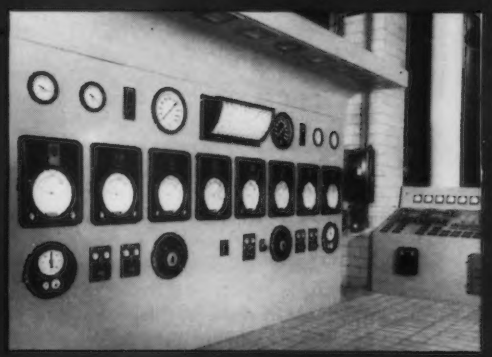

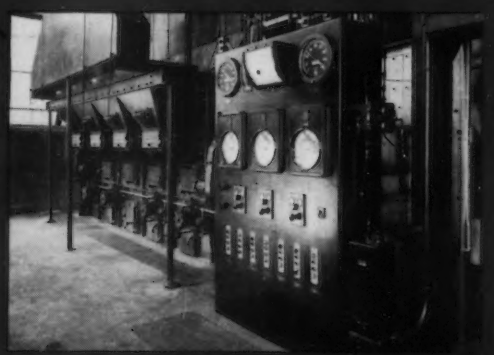

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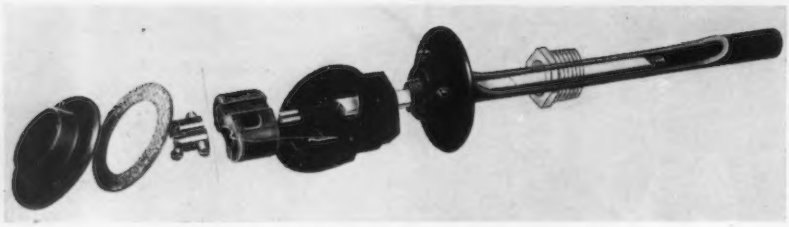


Courtesy of Minneapolis-Honeywell Regulator Co.
Figure 3—Thermocouple Assembly

for the obtaining of a known potential is not shown.

In operation, the slide wire contactor is moved along the slide wire until a point is reached at which no current flows in the circuit through the galvanometer as indicated by the galvanometer showing no deflection. At this point, the e.m.f. of the unknown exactly equals that fraction of the e.m.f. of the battery that constitutes the potential drop across R_1 and the portion of S to the left of C. Since R_1, S, and R_2 are known, S may be calibrated along its length directly in e.m.f. units (usually millivolts). It should be noted that, at balance, *no current* flows through the measured circuit. This is most important in industrial measurement applications since the effects of contact resistance, excessive leadwire resistance, and corrosion of parts are thereby minimized.

The Wheatstone bridge is a variation of the potential divider employed to determine the value of an unknown resistance. Very simply, if A and B in *Figure 2* are known resistances, and S is set to bear the same ratio to X as A has to B, then no current will flow through the galvanometer. Calibration of the slide wire may be made directly in resistance of the unknown. Instead of the conventional galvanometer connection, the so-called Siemens three-wire lead is shown in the sketch. This arrangement is widely used in industrial applications to compensate for temperature effects on lead-wire resistance. The simple Wheatstone circuit is subject to some errors so that modifications of it, to eliminate slide-wire resistance and other inherent errors, are now usually employed.

Thermocouple Pyrometers

Thermocouple pyrometers are possibly the most commonly used and most frequently abused instruments in any mill. Modern instruments of this type are built to stand an amazing amount of abuse, both necessary and otherwise. Nonetheless, the wise operators will find that the proper handling of these valuable tools will pay big dividends.

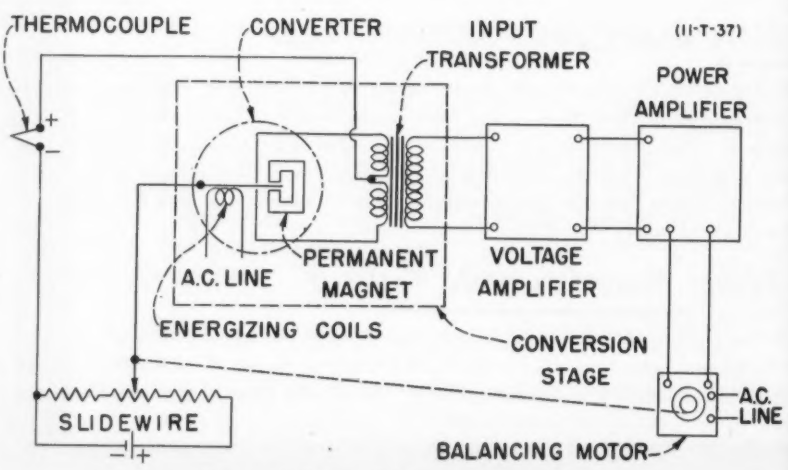
First of all, there is the actual measuring element itself, the thermocouple. An exploded view of a complete thermocouple assembly is shown in *Figure 3*. Note that the actual sensitive bimetallic junction, the e.m.f. of which varies with temperature, is encased in a rugged protection tube. Protection tubes are vital for most applications if there is danger of mechanical damage or chemical attack. But do not take the protection tube for granted. Protection tubes may corrode out, or get broken, and then what happens to the thermocouple? Then too, protection tubes always mean lag in response, to some degree. In some control functions, such lag must be minimized so that protection must be reduced or eliminated.

There is only one answer to the thermocouple problem and that is preventive maintenance. Regular inspection and frequent calibration of all thermocouples is essential to satisfactory application. Furthermore, be sure that new installations or replacements employ the right type of thermocouple assembly for the job, and, even more essential, be sure the thermocouples are located where they will measure what they are supposed to measure.

It should be noted that two types of thermoelectric effects are involved in generating the e.m.f. that is measured in a thermocouple circuit. Any bimetallic junction will have a certain e.m.f., the value of which will vary with temperature. But a mere junction of two metals is not a circuit, and there must be a circuit in order to have a flow of current and in order to determine the value of an e.m.f. by means of some detecting instrument. Thus, you see, the e.m.f. of a single bimetallic junction, the so-called Peltier e.m.f., cannot be determined all by itself. A second junction, the reference junction, must be introduced in order that there be a closed circuit. Now a measuring device may be inserted anywhere in the closed circuit to determine the potential of the one junction with respect to the reference junction. If both are at the same temperature, there is no net e.m.f. As the temperature of the outside junction changes, that of the reference junction remaining constant, the e.m.f. changes in a regular manner.

So far only the first thermoelectric effect, the Peltier effect, has been mentioned. One cannot measure a Peltier effect without also encountering the Thomson effect. This is the e.m.f. set up along a single conductor by a temperature difference between its ends. In the calibration of a thermocouple, and in its operation, both effects appear together to give the net e.m.f. that is observed.

Because thermocouple materials are quite expensive, it is usually economically impracticable to use lead wires of the same materials as the thermocouple. Industrially, therefore, the connections between the head of a thermocouple unit and the recording or indicating instrument are always made with compensating leads. These lead wires are made of alloys whose thermoelectric characteristics, particularly with regard to Thomson e.m.f., match those



Courtesy of Minneapolis-Honeywell Regulator Co.
Figure 4—Schematic Diagram—Electronic Potentiometer

of the thermocouple materials. Always use the proper type of compensating leads in connecting your instruments. Never use ordinary copper wire!

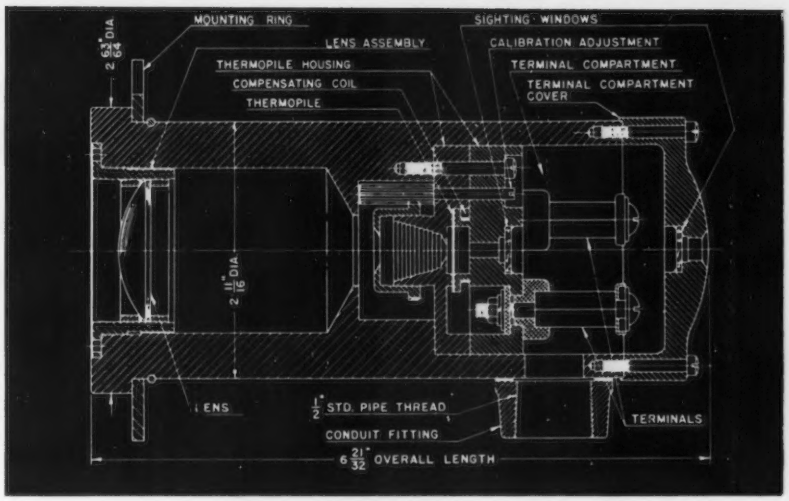
The indicating or recording element of an industrial thermocouple pyrometer is most likely to be an automatic potentiometer calibrated directly in degrees if the installation is permanent and if high accuracy is desired. In some installations, galvanometer (millivoltmeter) type indicators are used because of lower cost. It should be remembered, however, that galvanometer type instruments require that a current be flowing in the measuring circuit at the time of reading. Thus, corrosion of contacts or thermocouple, or high leadwire resistance may introduce errors in reading.

Modern automatic potentiometers are truly null-reading instruments but have introduced electronic detecting circuits in place of the galvanometer. Instruments produced by such companies as the Minneapolis-Honeywell Regulator Company, the Leeds and Northrup Company, and the Foxboro Company belong in the class. Such devices are much less sensitive to mechanical shock than are earlier types employing mechanical balance of a sensitive galvanometer. A schematic diagram of a typical automatic electronic potentiometer is shown in *Figure 4.* This particular model, the Honeywell "Electronik" employs a vibrating reed converter.

Many of these instruments have provision for automatic standardization (against a built-in standard cell) at set intervals, say, once an hour, or once a shift. A large number of models in use, however, rely on a semi-automatic standardization initiated by push-button. Be sure your operators standardize at least once a shift. A pyrometer not standardized for a week may read 30 degrees off!

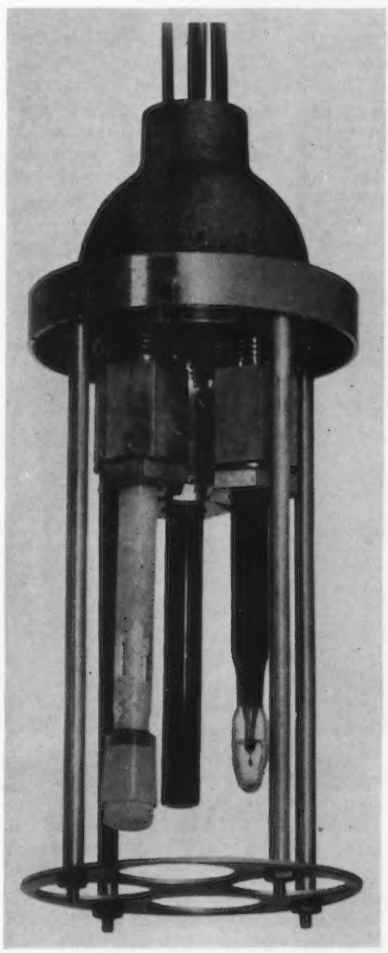
One last word on thermocouple pyrometers: Many laboratories have portable millivoltmeter type pyrometers with a variety of thermocouple heads, needle probes, ribbons, discs, etc., which are occasionally brought into the mill for special jobs. On occasion also, these devices are compared with permanently installed mill instruments. Only rarely will the two agree within a few degrees. Any disagreement may well be the fault of either or both, instruments or it may be because the two instruments are not actually measuring the same temperature.

The following procedure is suggested for the use of portable instruments: 1. Calibrate regularly according to standard procedure and prepare an error curve; 2. Check *every day* at the ice point, (0°C.) the water point (100°C.) and, if necessary, the sulphur point (444.6°C). 3. Remember that even when so calibrated, a portable millivoltmeter instrument is not equal in precision or accuracy of an industrial type automatic potentiometer in good working order. Only the best of laboratory potentiometers serve to calibrate these industrial devices.



Courtesy of Minneapolis-Honeywell Regulator Co.

Figure 5—Radiation Pyrometer—Cross-Section



Courtesy of Beckman Instruments, Inc.

Figure 6—Electrode Assembly for Industrial pH Measurement

Radiation Pyrometers

The temperature of certain operations in a pulp mill is more conveniently determined by the use of radiation pyrometers than with thermocouple installations, particularly where temperatures are excessively high or where the material to be measured is both hot and corrosive.

Most radiation pyrometers measure the amount of radiation coming from the object whose temperature is to be determined by means of multiple thermocouples, although some use resistance thermometers, and others use photoelectric cells. The detecting head of a typical industrial unit is shown in *Figure 5.* Automatic potentiometers, or automatic bridges coupled to these detecting units, are usually calibrated directly in temperature of the emitting substance.

Time does not permit a discussion of the many factors that go into the calibration of a radiation pyrometer. Suffice it to say that it is often necessary, and always desirable, for a competent instrument man to perform the final calibration check on the instrument set up in the process where it will be used permanently. Any material changes in the process involved or in the set-up of the unit may require a recalibration of the instrument.

pH Meters

Glass electrode pH meters have found wide acceptance in the pulp and

Figure 7—Laboratory pH Meter (Beckman Model G)

paper industry. They are useful in the control of all processes from pulping and bleaching through stock preparation and wet end operation. Automatic *control* of many such operations, based on pH measurement is now commonplace. For example, addition of alum solution at the consistency regulator is often controlled automatically according to the reading of a pH detector unit at the head box.

The basic detecting element in practically all commercial pH meters today is the glass electrode. In principle, the potential set up across a glass diaphragm by the difference in hydrogen ion concentration of two solutions is employed for the measurement of an unknown hydrogen ion concentration. The electrode itself consists of a sealed glass thimble containing a buffer solution of known hydrogen ion concentration. A platinum wire sealed into the upper portion of the glass thimble furnishes electrical contact with the buffer solution. Just as the e.m.f. of a single bimetallic junction is of no use for measurement unless a circuit is established, so the potential of a single electrode is also of no use unless a second electrode is introduced and a closed circuit completed on which electrical measurements may be made. Thus the second essential element is a so-called reference electrode, one that will have a constant potential irrespective of the hydrogen ion concentration of the solution being measured.

Let us envisage for just a moment the circuit, one element at a time. First, there is a glass electrode dipping in solution of unknown hydrogen ion concentration. The unknown is on one side of the glass diaphragm, the buffer on the other, the lead wire that contacts the buffer may be extended to connect to an external circuit. In order to close a circuit, however, some direct contact must be made with the unknown solution. It will not do simply to immerse a carbon rod, or a platinum wire, in the solution for the purpose of making contact with the external circuit. The potential of such an electrode with respect to the solution will change with change in the hydrogen ion concentration. This will defeat the attempt at measurement. It is not necessary that any other electrode touch this solution, however, if it may be connected electrically to another solution by means of a so-called salt bridge. Then, if this second solution is maintained at a constant concentration, any convenient electrode material may be used to establish contact with the external portion of the circuit.

In practice, the calomel reference electrode has been found most satisfactory for this purpose. The actual electrode, mercury and mercurous chloride in a porous tube, is in contact with saturated potassium chloride solution. This entire assembly, properly termed a half-cell, is enclosed in an outer glass tube. The outer glass tube is immersed in the unknown solution. One more feature is essential, a salt bridge must be established between the potassium chloride solution inside and the unknown solution outside. This is readily done by perforating the outer glass tube at a single point, so that potassium chloride may leak out very slowly and establish contact in so doing. The glass electrode and calomel reference electrode may be seen in *Figure 6,* which is a photograph of a typical, industrial-type pH detecting unit. The glass electrode may be seen on the right and a sleeve type calomel electrode is on the left. The black tube in the center is the bulb of a resistance thermometer.

While the potential of a glass electrode with respect to the calomel electrode may be appreciable in some cases, the electrical resistance of the diaphragm, however thin it may be, is so great that the current possible in the circuit is necessarily almost infinitesimally small. This means that an ordinary galvanometer type millivoltmeter cannot be actuated and there is even insufficient current available to obtain a balance point with ordinary sensitive potentiometers. It is thus necessary that a direct current amplifier be inserted in the circuit ahead of a potentiometer or galvanometer as a recording or indicating element.

Portable pH meters are marvelously compact instruments, considering all the complicated factors involved in making the measurement. It should be apparent from the preceding discussion, nevertheless, that the measurement is so complicated that it cannot be considered fool-proof with any instrument. In any type of instrument, it is essential that the sensitive end of the glass electrode be clean and free of scratches. Also, the small perforation in the calomel electrode assembly must be kept open and this electrode kept filled with saturated potassium chloride. In any event, microscopic amounts of impurities are bound to collect on the surface of the glass electrode, so it is always necessary to standardize an instrument against a solution of known pH before using. pH determinations are very sensitive to changes in temperature. For laboratory and portable-instrument determination, measurement of solution temperature compensator on the instrument, suffices. In industrial installations, a resistance thermometer is incorporated in the detecting unit and automatic compensation is provided electronically.

The laboratory, battery operated, potentiometer-type instrument, see *Figure 7,* has reached a highly satisfactory stage of development. It is reasonably portable, requires very small (3 ml.) portions of solution, and is capable of high precision and accuracy if not subject to mechanical shock. The line operated models are usually less satisfactory than the battery-operated types, primarily because the highly sensitive

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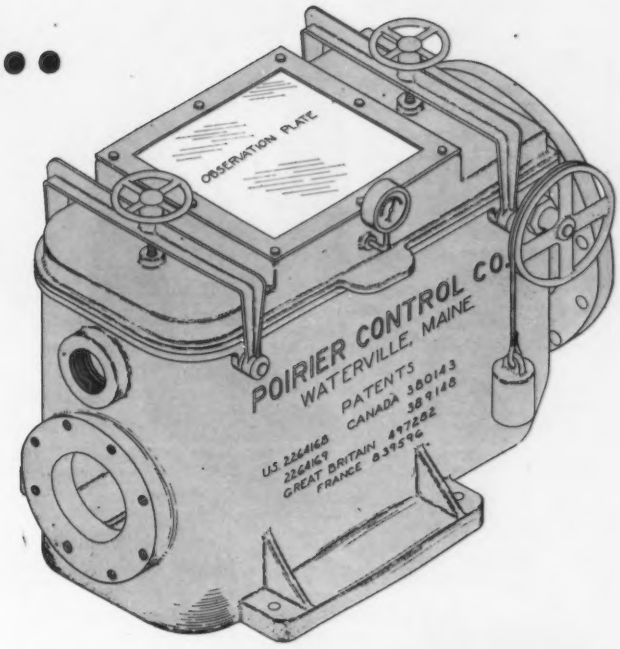

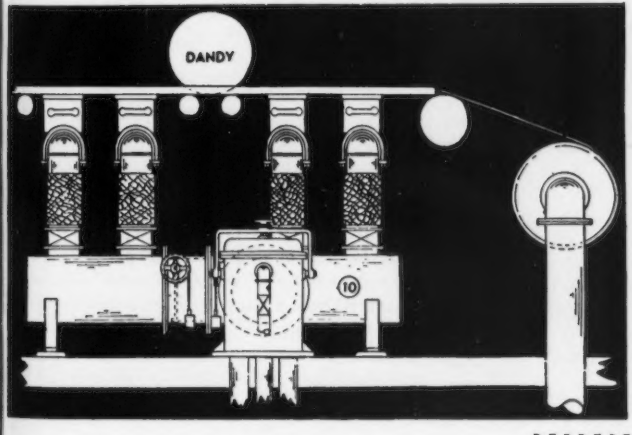

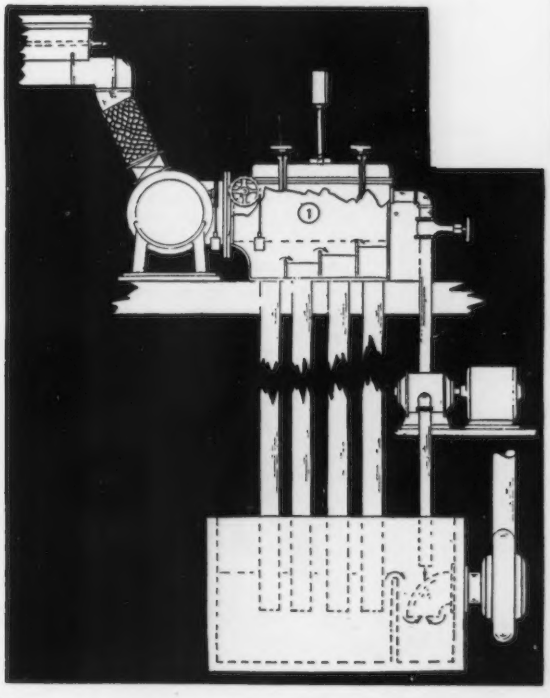

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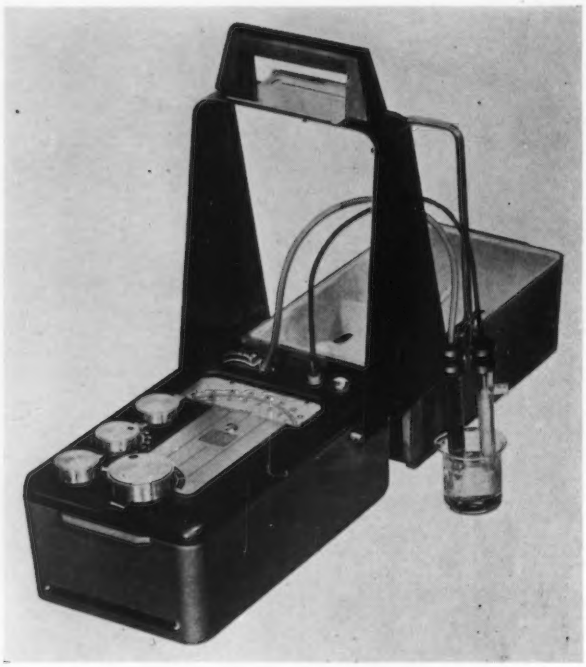

Figure 8—Portable pH Meter (Beckman Model N-2)

direct current amplifier is adversely affected by fluctuations in line voltage.

Unfortunately, the history of the galvanometer-type, direct reading, portable pH meter has been less favorable, at least until recently. These instruments are inherently less precise than potentiometer-type instruments. That, in itself, is no fault, for the usual application contemplated. However, early models often became distressingly inaccurate in use, presumably because of the effects of mechanical shock on the electronic tubes and of moisture on resistors. Today, however, the leading manufacturers have evolved moisture-proof and shock resistant models, as shown in *Figure 8,* which should have a good life of accuracy in portable service about the plant.

Industrial type instruments for permanent plant installation have likewise reached a high degree of perfection and may be used with complete confidence, if subject to regular calibration, checking, and maintenance.

In closing the subject of pH meters, a few trouble-prevention hints are in order. (1) Follow manufacturer's instructions for keeping the glass electrode in good working condition. (2) Do not use ordinary glass electrodes continually at pH values above 9. Such ordinary electrodes may be severely damaged by such use and will not give accurate readings in that range anyway. Special high-range electrodes are available for alkaline solutions. (3) Maintain the calomel electrode in satisfactory condition. (4) Standardize often against a buffer of known pH that is in good condition.

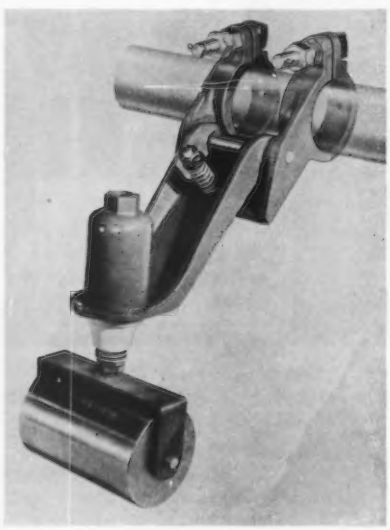

Figure 9—Detecting Head—Honeywell Moist-o-Graph

Moisture Detectors

The moisture content of a sheet of paper is most commonly determined in the laboratory by weighing it, oven drying, and reweighing. This is obviously not satisfactory for mill control purposes because of the time factor involved. Laboratory and mill instruments have been developed which are based on the Wheatstone bridge principle, since the electrical resistance of a sheet of paper is primarily a function of its moisture content, if such other factors as thickness, rosin and alum content, fillers and the like remain constant. The qualifications just listed remain the greatest drawback to efficient application of these instruments.

In *Figure 9* may be seen a photograph of the detecting head of one type of electrical moisture meter for continuous recording of sheet moisture of the machine, the *Honeywell* "Moist-o-Graph." The detector roll makes electrical contact to ground through the sheet and the drier drum. Similar contact to ground is made at the recording instrument and a Wheatstone-type bridge circuit is established. An automatic balancing bridge is employed and the chart or scale may be calibrated directly in terms of percent moisture. This arrangement is quite satisfactory if good control of basis weight, or thickness, is maintained and if there is little variation in the electrolytic constituents of the sheet.

Thickness or Basis-Weight Gauges

Various mechanical, pneumatic, and electrical devices have been marketed for the continuous measurement of the thickness of paper emergent from the machine. These devices, all of which are displacement gauges, but not all of which require physical contact with the sheet, have had a varying degree of acceptance. It is perhaps understandable why the mechanical type, which requires physical contact of a roller with the sheet, has encountered opposition among operators, but the somewhat limited acceptance of the other types is more puzzling. The principal objection seems to be that thickness can be measured at only one, or a few points across the sheet.

Recently a device employing an entirely new principle has appeared on the market that really gives a continuous record of basis-weight rather than thickness. This device, known to be marketed by Tracerlab, Inc. and by Industrial Nucleonics, Inc., makes use of the absorption of beta radiation by any material as a basis of measurement. The absorption of beta radiation is almost solely dependent on the mass of material, independent of its composition, interposed between a beta emitter and the radiation receiver of a detecting unit. If the beam of beta radiation is concentrated in an area of given size, mass per unit area may be directly determined from the amount of radiation that reaches the receiver. An ionization chamber as a radiation receiver may be coupled through an appropriate amplifier to an automatic recording potentiometer for this pur-

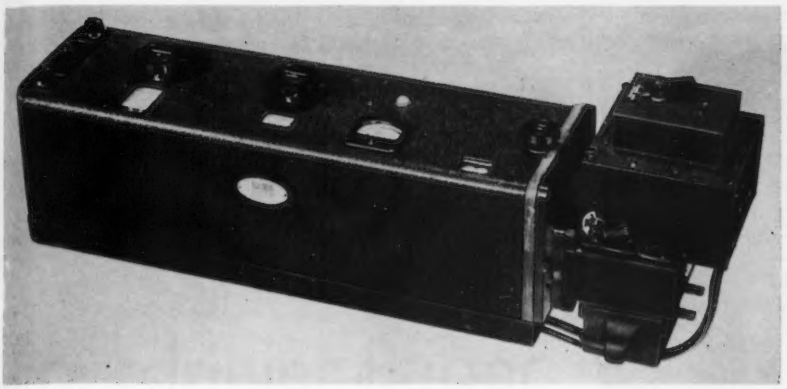

Figure 10—Quartz Spectrophotometer (Beckman Model DU)

pose. It should be noted that this instrument requires no physical contact with the sheet and that a traverse of the sheet, giving basis weight at any point across the sheet, up to a limit of 48 inches from the edge for present installations, is possible. The beta emitter has a working life of many years, is automatically standardized every half hour, and is not hazardous to personnel.

Evaluation of the usefulness of this type of instrument in the control of machine operation is still in progress. The potentialities of such a device are certainly very great.

Spectrometers

In closing this rather rapid synopsis of but a few of the types of instruments pertinent to pulp and paper mill operations, I would like to mention a type of instrument now confined to the laboratory that may some day be of great value in the mill where color is a problem. That device is the spectrometer, sometimes called the spectrophotometer, which is intended to measure either the absorption or the reflectance of light of particular wavelength from any convenient specimen of material.

Color is at best defined subjectively, while control based on instrumentation must rely on completely satisfactory objective definitions. Modern optical and psychophysical methods have progressed to a sufficient degree that an objective test of any colored surface is now available whereby it can be stated with assurance whether or not an apparent match will be obtained under standard illumination. This test, as outlined for paper in TAPPI Standard T 442 m-47, involves expensive apparatus and long calculation and is not, as it stands, suitable for mill control. Right at the moment, visual comparison under a standard lamp is much the better procedure. It is to be hoped, and expected, that techniques for the objective evaluation of color will be simplified and improved to the extent that they may one day serve a control function in paper mill operation.

Meanwhile, instruments for the determination of color characteristics are finding their way into pulp and paper mills. For example, experiments are in progress in several institutions regarding the feasibility of following the progress of cooking by objective determinations of the color of the cooking liquor.

Spectrometers for the visual range fall into three general classes. In order of increasing efficiency in resolution of the spectrum, and also in order of increasing cost, they are filter, grating, and prism instruments. The basic principle of all is the same. Light of a narrow band of wavelengths either is passed through (for absorption measurements) or reflected at an angle from the colored body and the amount of radiant energy transmitted or reflected, as the case may be, determined by means of a photocell and appropriate measuring circuit. This energy transfer is compared with that transmitted by distilled water (for absorption experiments) or reflected by a standard white (magnesium oxide).

The three instruments differ in the means whereby the fraction of light (band of wavelengths) is selected. The first uses colored filters designed to pass only light of a few limited wavelengths; the light so transmitted seldom approaches "pure" light of a single wavelength. The band width ranges from 20 millimicrons to 60 or more.

The second type disperses white light into a continuous spectrum by means of a ruled diffraction grating. A narrow aperture permits only a portion of this spectrum to pass to the subject to be illuminated. The band width on this type is about 25 to 30 millimicrons.

The third type employs quartz prisms to accomplish the dispersion of white light into a continuous spectrum. The

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Fig. 1

PAPER HYGROSCOPE (Lithographic Technical Foundation Model), indicates the difference, in terms of relative humidity, between the pressroom air and the paper stock.
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SURFACE MOISTURE INDICATOR, provides a simple, quick and accurate means of determining the moisture in paper.

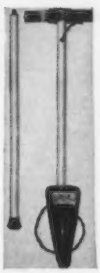

Fig. 2

SURFACE PYROMETER, Fig. 2, indicates roll surface temperatures. It is made in the hand model or with an extension attachment to reach the hard-to-get-at places.

Fig. 3

pH RECORDER, Fig. 3, provides a continuous record of pH in aqueous solutions in the manufacture of paper. If pH of the stock is too high, an insufficiently sized sheet results. If pH is too low, not only is sizing uneven, but large quantities of alum are wasted.

Fig. 4

DIRECT READING INDUSTRIAL pH METER, Fig. 4, is especially designed and ruggedly built for plant use. All-electric, it is so simple that unskilled workers can easily use it.

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band width varies with the wavelength to be used, and the intensity of illumination needed, but usually is of the order of one to five millimocrons. Band widths as low as 0.1 millimicrons are possible. This is truly monochromatic radiation. A quartz prism spectrophotometer set up for reflectance measurements on paper is illustrated in *Figure 10.*

Conclusion

The best asset anyone employing instruments in his daily occupation can have is a healthy curiosity. Read all the books, articles, and instruction sheets you can find about your instruments. The more you know about them, the better you can have them serve you and the more efficient will be the operation you supervise.

Fourdrinier Paper Machines—Wet End

Paul Baldwin[1]

Graduated—Syracuse University 1936—B.S., Ch.E.; Institute of Paper Chemistry—M.S., Ph.D.; with Scott Paper Co. since 1940

Introduction

In preparing this discussion of the wet end of a paper machine, it was necessary to consider the time allotted for this presentation and where our emphasis should be placed. It was thus decided to concentrate primarily on the Fourdrinier machine and to divide the discussion according to the section of the paper machine from the head box through the press section.

The Head Box

First, let us discuss the headbox. The function of the head box is to deliver stock to the forming area or to the slice at the proper velocity, thoroughly and uniformly mixed and free from cross currents, turbulence and eddies. In other words, the exact quantity of stock and water and at identical pressures must be delivered to each inch of slice opening across the entire width of the paper machine. As the paper industry has rapidly increased the width and speed of paper machines, the design and operation of the head box has become more critical, and new and radical designs have resulted.

If you were called to design a head box the following specifications would undoubtedly be given you.

1. There shall be no surging at its entrance.
2. There shall be no dead areas in the box.
3. There shall be no corners or sharp angles.
4. The head box must provide a uniform delivery to the slice proper.
5. A uniform, homogeneous fiber dispersion must be maintained.
6. The head box should be so designed as to eliminate entrained air.
7. Fiber flocculation must be prevented in the head box.

As the stock leaves the screens that precede the headbox it can be assumed that it is fully dispersed. Actually, dispersion of the fiber is one of the important functions of the screens. The elimination of the cross currents and the maintenance of uniform dispersion requires exactly opposite treatments. ments. A large quiet head box will eliminate currents but when we have that the fibers will tend to coagulate. A strong agitation will mix the fibers thoroughly and disperse them but it will create the objectionable cross currents and eddies that we try to avoid.

Thus, the head box design is, at best, a compromise between the two extremes. The head box should always contain interference devices to disperse fibers and should also have streamlined flow passages. Experienced operators will say that stock must be kept alive, that they must keep control of the stock by agitation throughout its passage through the head box to prevent floc formation. It was soon found that a smooth flow at relatively low speed, with the fibers at rest relative to one another, give conditions that promote flocculation, slime formation and stock accumulation in the dead spots.

The interference devices incorporated in the head box to promote the required agitation have been designed in many different ways. They are designed to constrict the flow of the stock and thereby to increase its velocity. A momentary speed increase followed by a sudden speed decrease creates small eddy currents which break up fiber flocs. Pin racks, perforated plates and rolls have all been used for this purpose.

The pin racks which is one of the earliest designs of interference devices is illustrated in *Figure 1.* The pins were put in the path of the flow of the stock and water mixture; thus accomplishing a reduction in area through which the stock and water could flow. At the point of the reduced area the stock velocity was increased and upon leaving the rack the velocity of stock and water again decreased.

Perforated plates were also used to accomplish the same purpose but it was found that the fibers tended to deposit and to string on both the perforated plates and pin racks. This caused a shive problem as well as a

[1] Assistant Vice-President, Scott Paper Co., Everett, Wash.

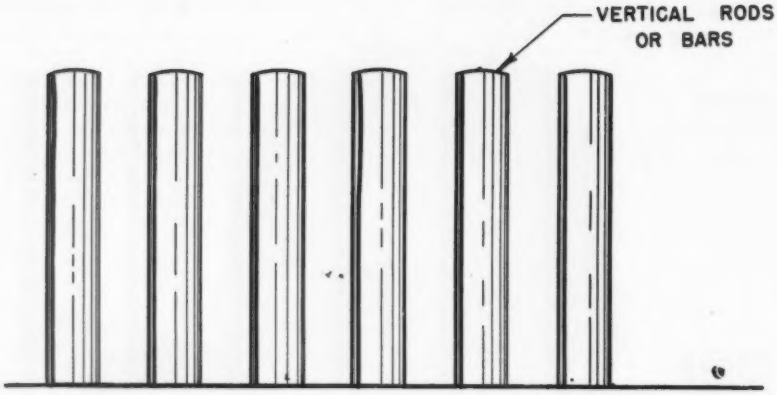


Figure 1—Pin Rack

lump problem on the paper machine. To overcome this serious negative the rectifier roll was developed and is shown diagrammatically in *Figure 2.*

The rectifier roll is a hollow roll, the shell of which has been perforated with round holes. The holes will vary in size throughout the industry from three quarters to one and one-half inches in diameter. In recent years the rectifier roll has been equipped with internal disks spaced about six inches apart. The disks tend to prevent cross currents and thus aid in streamlining the flow. The perforated roll did eliminate the objection of fiber stringing and hang-up that was so prevalent with the use of the perforated plate and pin racks. Usually the perforated rolls are rotated within a speed range of from ten to thirty revolutions per minute. The rotary action is not for the purpose of stock agitation but is only to keep the fiber from collecting upon the surface of the roll.

As machine speeds have increased, the basic design of the head box has undergone a radical change. The engineers first confronted with this problem of designing for increased speeds reasoned that higher speeds required larger volumes of water per minute, and therefore larger, longer head boxes with many more passages were needed. *Figure 3* shows one of this type. This larger head box did help to eliminate eddy currents but it also allowed fiber flocculation and a circulation within the box as illustrated. With this type of circulation there is no real control of flow from the head box to the slice and the flow on the wire may be strong or weak at any given point. The weight variation across the wire could, therefore, be considerable.

Accepted practice in the design of a head box today is to reduce the size of the head box and to confine the stock flow in the box between plates or baffles. This design is shown in *Figure 4.*

In this case, the flow of the stock and water is controlled so that the erratic circulation found in the large box is virtually eliminated and a uniform distribution at the slice results. The upward flow caused by the baffles also allows the elimination of air from the stock.

The Slice

The stock and water flows from the head box to the slice. The primary function of the slice is to deliver a sheet of liquid to the wire having uniform thickness, equal velocity across the entire wire width. The velocity of the water and stock mixture flowing through the slice is dependent upon the height of the stock-water mixture above the wire. Normally, the height of the stock and water mixture above the wire is so adjusted as to allow the discharge velocity of the stock and water mixture to be the same as the running velocity of the paper machine wire. To determine the height of the mixture, which is normally called head, required to meet the proper discharge velocity the well known hydraulic formula, $V = \sqrt{2gh}$ is used, where: V = velocity of discharge, g = acceleration of gravity, and h is the head.

For example, if a paper machine is running at 600 feet per minute, it can be determined from the aforementioned formula that a head of 20 inches above the wire will be required to deliver the stock water mixture to the wire at 600 feet/minute, or the speed of the wire. If a machine is running at 1200 feet/minute a head of 80 inches will be required.

A paper machine slice is essentially an orifice and the following figures illustrate five types of orifices which will cover practically all of the basic designs used for slices today.

The orifice shown in *Figure 5* represents a standard sharp edged type of orifice. The discharge jet contracts as it passes the edge and then expands to its former thickness. It has a discharge coefficient of approximately 0.62 and, therefore, reduces the discharge by this amount.

The second, *Figure 6,* is a sharp edged orifices having one straight wall. In this particular type "B" the contraction is less than that caused by the first type and has a discharge coefficient of about 0.8.

In "C," *Figure 7,* the curved orifice, the discharge coefficient is about 0.90. In "D," *Figure 8,* the tube shaped orifice has a discharge coefficient of 0.95.

The last orifice, "E," *Figure 9,* is the nozzle type orifice and it has a discharge coefficient of 0.97.

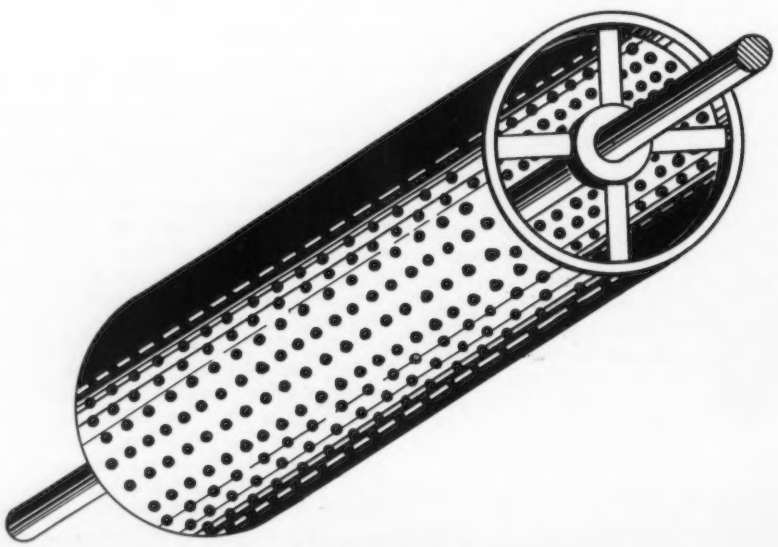
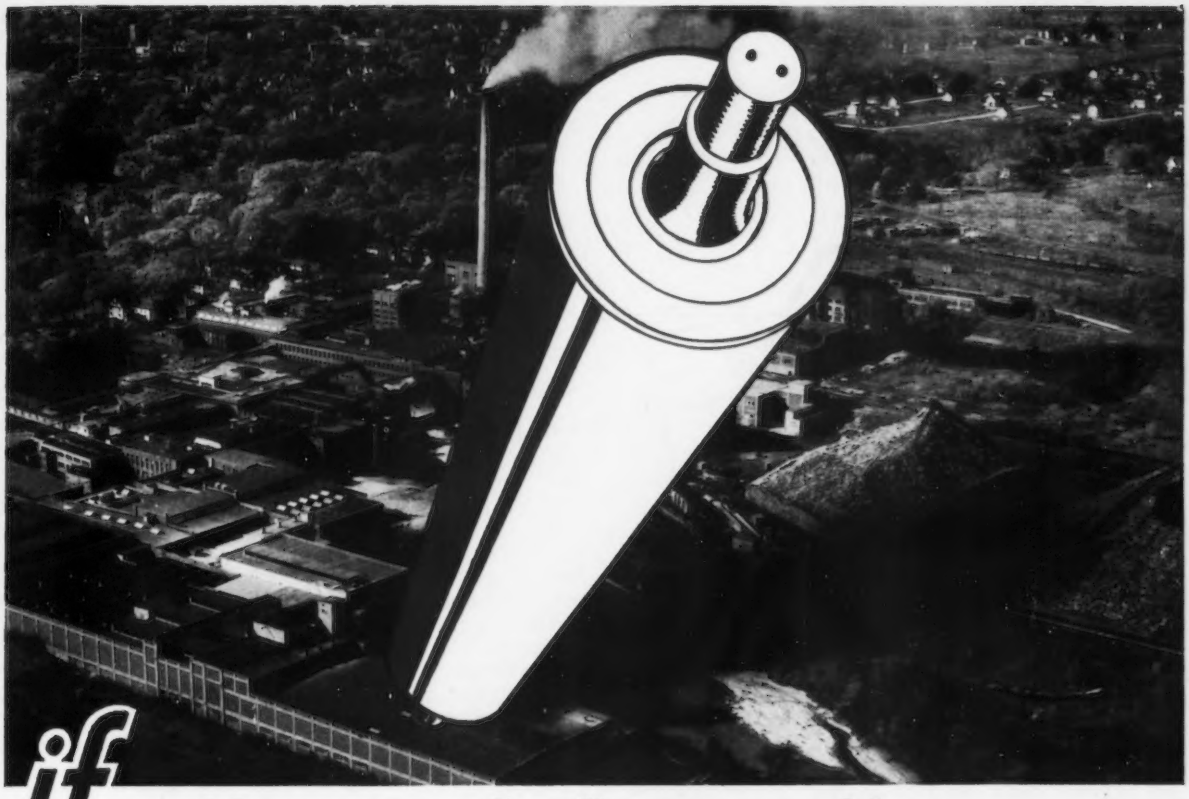


Figure 2—Rectifier Roll



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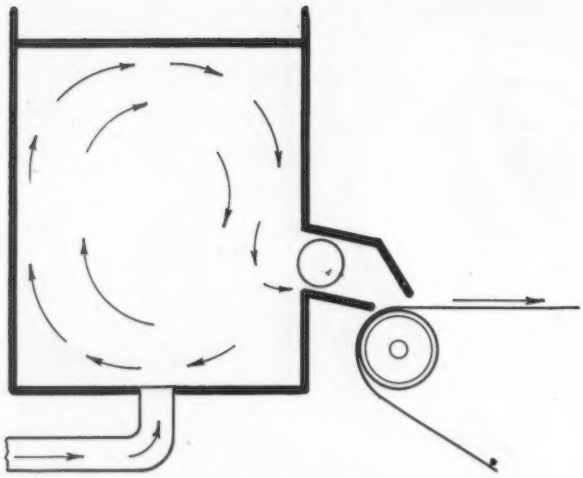

Figure 3—Large Head Box

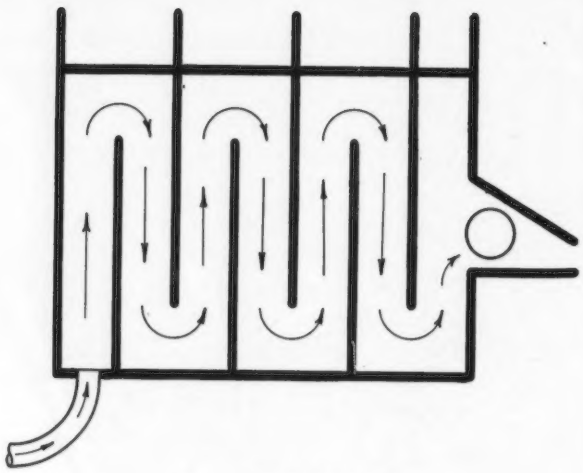

Figure 4—Baffled Head Box

By actual measurement, the discharge coefficient of a slice on a modern 232″ newsprint machine was found to be about 0.94, or very close to the coefficient characteristic of orifice "D" pictured in *Figure 8*.

Many variations from these basic orifices have evolved in paper machine designs, and a discussion of some of them follows. The *Voeth type slice* is shown in *Figure 10* and is one of the first type slices incorporated in higher speed paper machines. It is an orifice similar to "D" in *Figure 8*.

It can be noted from a study of *Figure 10* that the top lip of the slice can be raised or lowered in relation to the bottom lip. This is essential to provide a method for maintaining a constant head above the wire and still increase the quantity of flow through the slice. The operation of a paper machine on a grade or type of paper must be such as to deliver a constant amount of fiber at all times. The amount of water accompanying the fiber on to the wire may be varied to improve the formation or change the qualities of the finished sheet of paper. In other words, the consistency (pounds of fiber/pounds of water) in the head box can be varied and the adjustment of top lip of the slice will allow a constant head to be maintained above the wire. For example, if a machine is running at 12 feet/minute at a head of 80 inches and the machine tender wishes to reduce the head box consistency by adding more water, he can raise the top slice lip, increase the opening of the orifice, and still maintain a head of 80 inches.

The small hand wheels spaced uniformly across the width of the top slice lip are to provide a method of leveling the slice and provide uniform flow from one edge of the wire to the other.

The *Van de Carr slice* shown in *Figure 11*, was developed for the high speed newsprint machines in Canada and is still used today by many companies. This slice has a curved top lip rather than the straight lip used by the Voeth slice. The curved lip gives a nozzle effect and causes the water and stock to approach the wire on a plane parallel to it. The rectifier roll placed directly before the slice opening accomplishes the same purpose as those used in the head boxes—momen-

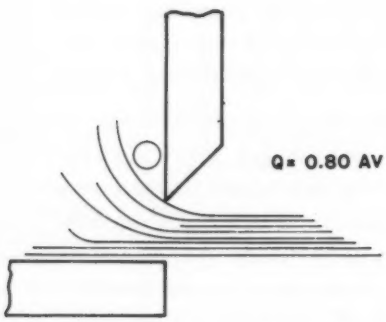

Figure 6—Orifice "B" One Flat Wall

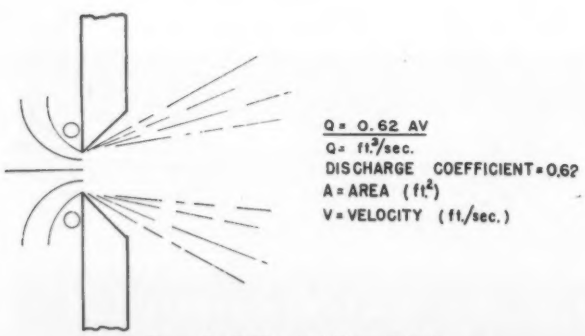

Figure 5—Orifice "A" Sharp Edged

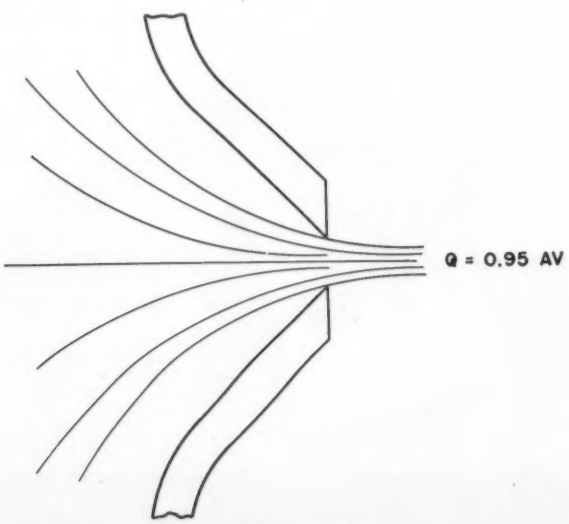

Figure 7—Orifice "C" Curved

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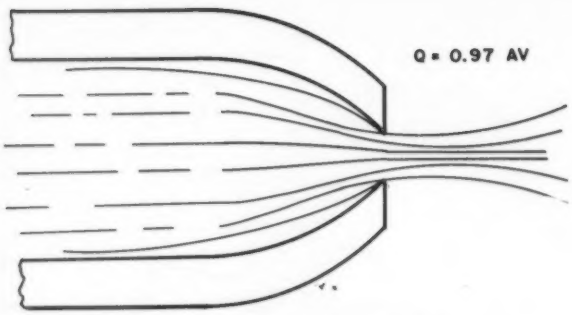

Figure 8—Orifice "D" Tube Shaped

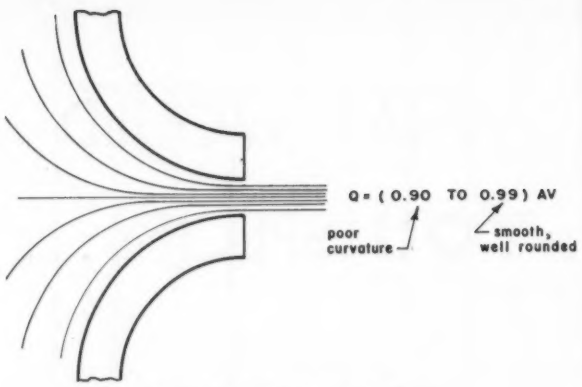

Figure 9—Orifice "E" Nozzle Type

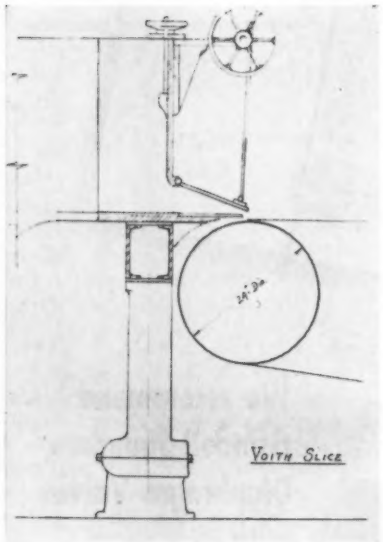

Figure 10

tarily increasing the velocity of the stock followed by a speed decrease creating small eddy currents which break up fiber flocs and randomly orient them. It is also provided with devices for raising and lowering the top lip and adjusting the lip across the machine to compensate for non-uniformity of flow.

The *Valley Pressure slice* is illustrated in *Figure 12.* This is actually an adaptation of the Voeth slice. The bottom lip of the Valley pressure slice is located directly over the center line of the breast roll and the top lip can be moved forward or backward wtih respect to the bottom lip. There is also an adjustment to change the angle of the top lip.

To operate the Valley slice as a pressure slice the top lip is adjusted so that it projects considerably past the center line of the breast roll and the bottom lip. The angle of the top lip is very steep and the stock and water is driven into the wire rather than parallel to it as is the case with the *Van de Carr* slice. This aids in dewatering and is especially effective with light weight papers. Since the water is forced against the unsupported wire by the entire pressure from the effective head behind the slice, the wire will sag to the point where deckle shoes are required to keep the water from squirting out at the sides of the slice.

Flow Eveners

As machine speeds have increased the head box has become one of the limiting factors on the machine. To obtain theoretical heads at speeds of 2000 feet/minute and over the head box must be of such height as to be ungainly. Thus the trend of the paper industry has been toward the elimination of the head box. To effectively eliminate or cut down the size of the head box, flow eveners have been designed which will distribute the stock uniformly across the full width of the machine without cross currents and in a uniform dispersion. The flow evener is attached directly to a single pass head box or pressure inlet. While there are many flow eveners available to the industry today, they can be divided into two types.

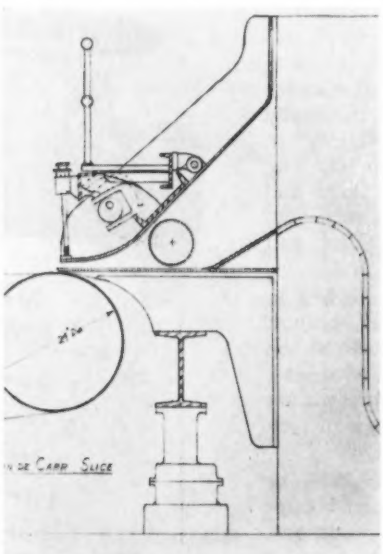

Figure 11

The first type is illustrated by the line diagram given in *Figure 13.* In this type the stream of stock coming from a single pipe, the outlet of the fan pump, is divided evenly into two streams and then to four streams then to eight streams where it is connected to the head box. If this distribution system is carefully designed, taking care that at each division an exact hydraulic balance is reached, an equal quantity of stock will be delivered to each unit width of the head box or slice. When one considers the enlarging of a stock line to the full width of a paper machine, it must be remembered that the maximum angle of divergence which stock will follow is 8-12° for rectangular cross sections and 6° for round pipes. At larger angles the stream does not diverge but

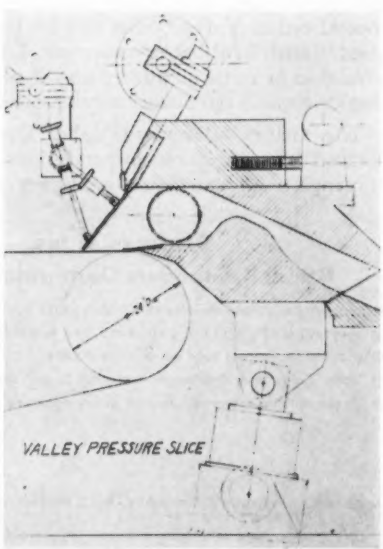

Figure 12

flows on through as a current surrounded by eddies and turbulence. Therefore, it is better to reduce the pipe sizes slowly with more division points.

The second type, shown in *Figure 14*, is sometimes referred to as the "Hydromatic Flow Spreader." In this case the water from the fan pump is split into two equal streams coming into a single chamber counter current to each other. The turbulence in this chamber mixes the stock and it is released through the slot into the head box or slice uniformly across the entire width of the machine.

The Fourdrinier Table

In this discussion the Fourdrinier table of the machine will be considered to comprise the entire section of the paper machine between the slice and the press section and is devoted to the forming of the sheet and the removal of water by the drainage process.

The Fourdrinier table is comprised of the following component parts: The wire; the forming boards, if any are used; the deflectors; the table rolls; dandy roll; suction boxes; breast roll; couch roll; the deckle; and the shake. *Figure 15* is a sketch of the table with these parts labeled.

The rate of drainage is most important and must be carefully controlled at all points along the Fourdrinier table. Drastic water removal before the sheet is set will result in distorted formation.

The wire is an endless belt made of wire cloth woven from brass, and bronze wire with mesh sizes chosen to fit the peculiar needs of the paper machine. It is the wire mesh that catches the fiber allowing the water to drain through into the pan below.

The table rolls are usually made of steel tube covered with rubber, micarta or plated metal and are of such stiffness and rigidity that they will not whip and vibrate to cause distortion formation. Solid table rolls draw water out of a sheet much the same as occurs when one touches the inside of a wet tent. The popular conception of the dewatering action of table rolls was that they acted as a pump pulling a vacuum at the discharge nip and drawing water through the nip as they turned. However, a theory developed by Cowan* explains this simply and tests indicate that his theory accurately accounts for all water removed by table rolls. *Figure 16* is a sketch of a cross section of a wire carrying stock in suspension across a roll. The thickness of the stock suspension over the wire is designated as "H," the head

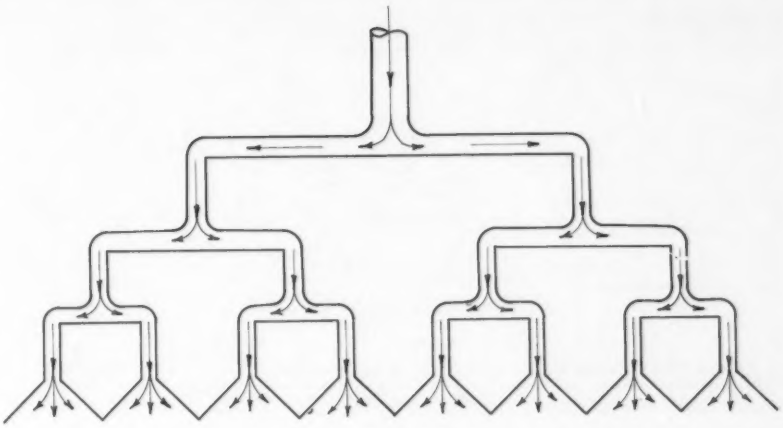

Figure 13—Flow Evener

above the wire. The semi-circle represents the circumference of a table roll. "R" is the radius of that roll.

If water is being extracted by the roll, the amount of water flowing out of "B" to "C" must be equivalent to the amount of water that is draining out from the wire from "A" to "B." According to Mr. Cowan the quantity of water that is being removed from the wire from "A" to "B" is equal to

$$\frac{4\ K^2\ Rgh}{V}$$

where "K" is the drainage coefficient and is dependent on the sheet weight and type of wire; "R" is the radius of the roll; "g" is the acceleration due to gravity; "h" is the head of stock suspension above the wire; "V" is equal to the velocity of the wire.

Looking at this formula, it is obvious that there are four variables that effect the water removal by a roll. These variables are:

1. The radius of the roll—the larger the roll the greater the water removal.
2. The head of the stock suspension above the wire.
3. The drainage coefficient.
4. The velocity of the wire — the higher the wire velocity the lower the drainage rate.

In this formula, there is no consideration given to the speed of rotation of the roll. Experimentally this has been checked by measuring the water removal of a roll while turning and then stopping the roll and measuring the water removal again. Such experiments have confirmed Cowan's theory.

In order to prevent water thrown by one roll from striking the roll ahead of it and thus being thrown into the sheet, deflectors are placed just below the wire and ahead of each table roll. In case the deflectors are used for only deflecting the water the blade is usually set ⅛" below the wire. In case the

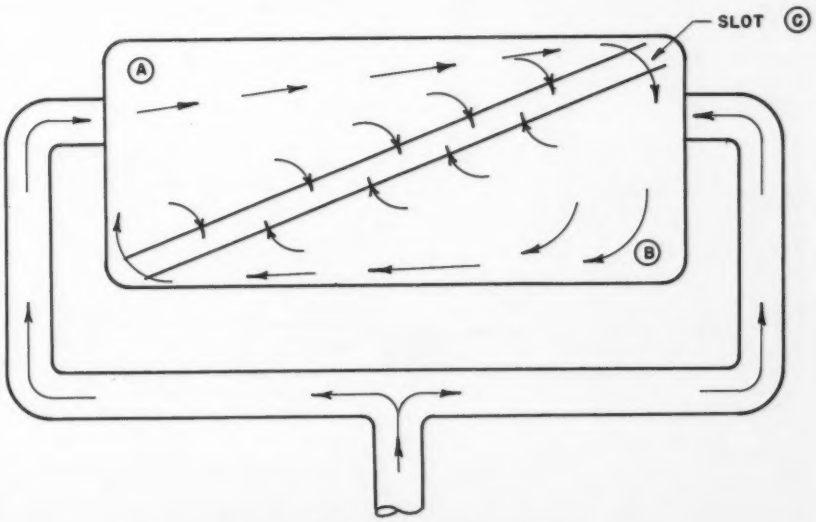

Figure 14—Hydromatic Flow Spreader

* Cowan, E., *Proc. Tech. Sect. C.P.P.A.*, 169 (1937). For a more exhaustive discussion see Sankey, C. A. and Cowan, E., *Chem. Eng. Progress 44*: 745-752 (1948).

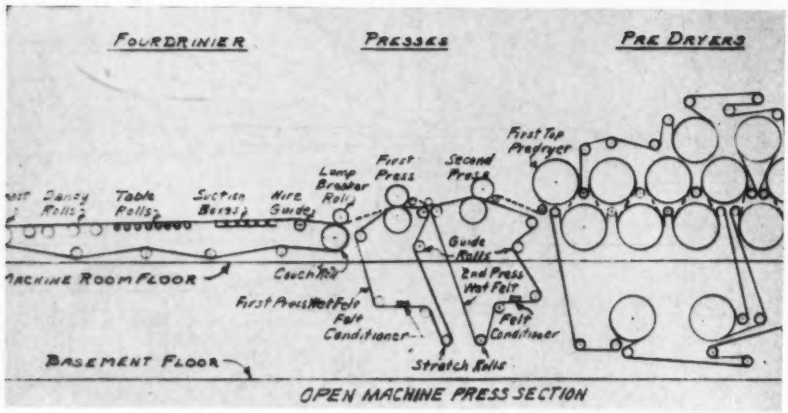

Figure 15

deflector is actually used to support the wire and to remove water from the sheet, it contacts the wire. As is shown in *Figure 15* the wire suction boxes are located after the table rolls and before the couch roll. Their prime purpose is to remove water from the sheet. The boxes are made of a non-corrosive metal such as bronze or stainless steel, are usually rectangular in cross section and are equipped with a perforated cover which supports the wire. The covers may be made of a hardwood, such as maple, hard rubber, composition or metal. Every precaution must be taken to keep the covers smooth, to decrease friction and wire ridges. Pistons seal the vacuum at each end of the box.

The first suction boxes handle most of the water and usually the vacuum is reduced purposely. A test of the water removal capacity of the suction boxes on a 234″ news machine running at 1100 feet/minute gave the following data:

Box	Vacuum	G.P.M. Water	C.F.M. Air
1	1.97	300	10
2	2.22	210	15
3	6.09	335	20
4	7.00	240	23
5	7.19	150	35
6	7.56	120	34
7	7.12	210†	12‡
8	7.46	275	8

† Dandy roll on this box.
‡ Sheet compacted by dandy roll.

An analysis of this table indicates that the vacuum was reduced on the first two boxes where water flow is high and air removal is low. After the sheet passes over the first box the sheet is set and thereafter very few fines get through the sheet.

The breast roll is located under the slice and acts as the turning point or pulley for the wire. Normally this roll is not driven but is pulled by the wire. It, too, removes water from the stock suspension on the wire. It is normally a steel roll, covered with hard rubber or a composition.

The couch roll on the modern machine is of a suction type having a perforated shell through which vacuum is applied from an internal box. The vacuum pulls air through the sheet drying it and compacting it. It is not uncommon to have a lump breaker roll riding on top of couch roll contacting the roll over the leading edge of the internal suction box. This roll is covered with extremely soft rubber and further compacts the sheet and presses out stock lumps to prevent breaks in the press section. The couch roll is the driven roll on the Fourdrinier table transmitting the power through the wire to the other rolls and in turn driving them.

The deckles are necessary to keep the stock on the wire and form the edge of the sheet. The width of the sheet can be changed by moving the deckles. The oldest deckle, still widely used, is the moving rubber deckle stap supported on pulleys at each end. This deckle strap rests on the edge of the wire and is moved by the wire. This deckle strap usually extends past the first suction boxes. The moving deckle strap is not satisfactory for high speed machines and stationary deckles have been substituted for them. These consist of a metal support which holds a thin strip of rubber in such a position that it bears on the wire lightly and thus holds the stock.

The shake on a Fourdrinier produces a series of short quick movements at right angles to the direction of the movement of the wire. The usual method gives the breast roll a maximum shake and the couch roll none. The shaking motion agitates and levels the sheet, helps distribute and mat the fibers together in a more compact and dense sheet. It also tends to break up the fiber alignment in the machine direction. The shake is not often used on machines running in excess of 1000 feet/minute because the fibers are under its influence such a short time that it accomplishes nothing.

The rate of drainage of water through a wire is also a function of stock freeness and the water temperature, or the water viscosity — the more free the stock and the higher the water temperature the greater the rate of drainage. Many mills that wish to increase

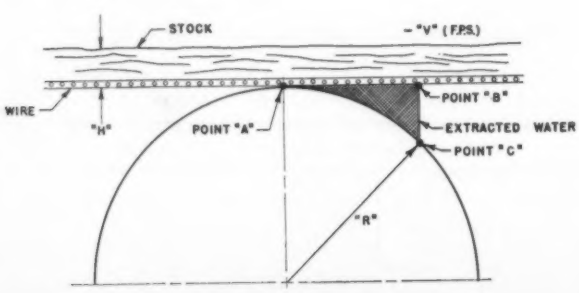

Figure 16—Mechanism of Water Extraction

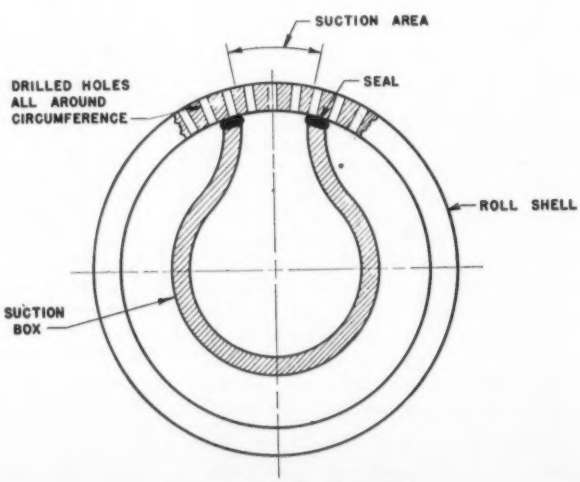

Figure 17—Suction Press Roll

the rate of drainage actually heat the stock suspension.

Water Removal at the Press Section

In the machine pictured in *Figure 15*, two sets of press rolls are shown directly after the couch roll. Both presses in this vacuum machine are suction presses. Many machines do have a plain third press which is used to smooth out the surface of the sheet for uniformity more than for water removal. In some cases the third press is used as a reversing press. When the press is reversed the sheet is brought through from the opposite side and the felt is brought in contact with the top side of the sheet, giving a felt pattern to both sides of the sheet.

Rather than spending time on a detailed description of presses and their operation, the discussion will be limited to the important variables influencing the water removal by a suction press. While discussing these variables it might be well to refer to the cross section of a suction roll in *Figure 17*.

The most important variables are as follows:

1. The time the sheet is in contact with the suction area of the roll

The time the sheet is in contact with the suction area of the roll is dependent on the speed of the machine and the width of the suction box in the roll. It is apparent that the longer contact time on the roll will give the greatest water removal at the press. Higher machine speeds have necessitated wider boxes in order that the same or longer contact times may be retained. Recently, presses have been developed for high speed machines having large diameter bottom rolls with boxes 24 inches wide and two top rolls sealing both the leading and trailing edges of the suction box in order that the time of contact could be extended.

2. The thickness of the shell

As the thickness of the press roll shell is increased its water removal capacity is decreased provided the other factors, i.e., speed, vacuum, etc., remain the same. The thickness of the shell should be considered as the thickness of the shell and the thickness of the jacket. During the operation of a high speed machine, very little water, if any, is taken into the suction box of the press. The water is taken from the sheet and felt into the drilled holes in the roll, held there and when the vacuum breaks on the trailing edge of the box the water is thrown out into the saveall pan around the roll. The vacuum pumps are actually displacing the air that is in the holes so that the water can enter them. The thicker the shell then, the greater the volume of air is that must be displaced before the water can enter the holes.

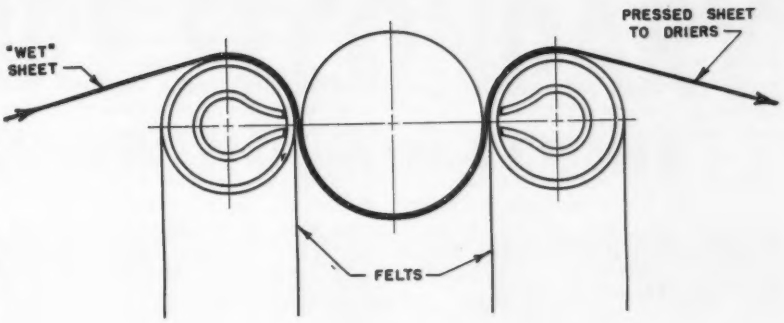

Figure 18—Dual Press

The industry has tried many ways to reduce the shell thickness of press rolls to increase their efficiency in water removal. One method successfully used is to run the suction roll without a jacket, using an exceedingly soft top roll. By eliminating the jacket the effective thickness of the shell is reduced appreciably and much better water removal has been obtained.

In the design of a press roll shell, the thickness of the shell is dependent on the stiffness of the metal being used. Therefore, more rigid metal alloys are being used, such as monel, for press roll shells. The more rigid metal allows the use of a thinner shell for the same press roll deflection at a given load.

3. The diameter of the holes in the shell and the amount of land area between holes.

The size of the holes in a suction press roll should be selected to be as large as possible to give maximum water removal but must not be large enough to shadow mark the sheet. The smaller the hole diameter the greater will be the negative effect of surface tension on releasing the water from the shell after the vacuum is broken. A new drilling pattern has recently been developed which cuts down on the land area between holes. By cutting down on the distance between holes the distance the water must travel to get into the holes is reduced and greater pressures can be used on the wet sheet without crushing it.

4. The vacuum applied to the roll.

The greater the capacity for air displacement the more efficient will be the press. The inches of vacuum as such cannot be considered as the final criterion for a good water removal but rather the amount of air pulled by the pumps. The wider boxes used in press rolls for high speed machines have required greater capacity vacuum pumps to make them fully effective.

5. The viscosity of the water being removed.

In the press section, as on the Fourdrinier table, the viscosity of the water is an important variable effecting water removal. The lower the viscosity of the water the more efficient will be the water removal in the presses. Here again the heating of the stock system and felt shower water will aid the operation.

The presses shown in *Figure 15* are of the standard vertical type. While these are more common, a more recent development has brought to many mills the dual press which is illustrated diagrammatically in *Figure 18*. This

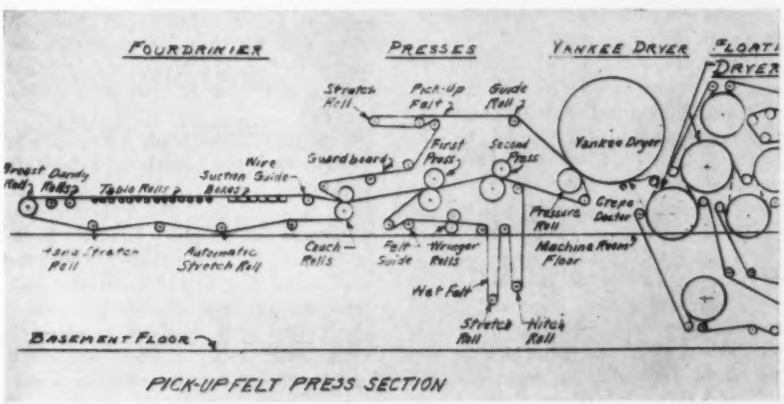

Figure 19

press is used in higher speed machines and does conserve space. In the dual press there is one large center roll with two suction press rolls pressing against it, one on either side. There is an individual felt around each suction roll. The dual press is giving satisfactory service and does the work of two presses while requiring considerably less space than the two vertical presses would require.

The Closed Machine

The closed machine is similar to the Fourdrinier except that the sheet is carried from the couch to the presses on a pick-up felt. *Figure 19* is a schematic drawing of a closed machine used for the manufacture of tissue. Until recently, pick-up felts were used only on machines manufacturing very light weight papers, but increased speeds have demanded more safety in carrying the sheet from the couch to the presses on other papers such as kraft liner, newsprint, etc. As a result, the pick-up felt has been installed on machines for that purpose with very satisfactory results.

Actually, the Fourdrinier table for a closed machine is very similar to that illustrated in *Figure 15,* except that the couch roll is not equipped with suction. The bottom couch roll is grooved with a spiral pattern to allow the water to get away rapidly when the top couch is lowered on it. Paper will always leave a rough surface to go to a smooth surface and thus when the sheet carried on the wire is contacted by the pick-up felt the sheet leaves the wire and goes to the pick-up felt where it is carried to or through the presses. More recently, the top couch roll has been made as a suction roll, actually sucking the sheet from the wire to the felt.

Paper Machine-Wet End

Wesley Corbin

M.E. Cornell 1931, M.S. Chemical Engineering, Maine 1934. 1931-1944, Scott Paper Co., Paper mill and converting production—five years; Finishing development—four years; Paper mill development—four years. 1944-1948, Associate of Francis Chilson, Industrial Consultants, New York City, paper, drug and cosmetics field. 1948-present, The Bagley & Sewall Co.—1948-1951, Director of Research and Development; 1951-present, Chief Engineer.

Introduction

This project of the pulp and paper school in cooperation with their alumni in bringing outside lecturers, good and bad, to talk to you men about the various problems you will face when you go out into the paper industry, is an opportunity for both the students and industry. There is a terrific need for technical help in the pulp and paper industry at the present time. You are very fortunate as compared to conditions under which I entered the pulp and paper industry. I graduated as a mechanical engineer and had no idea how paper was made until after I graduated. You, at least, will have had some insight as to the technical, theoretical and practical experience required in the paper industry.

I have been asked to speak on the wet end of the paper machine. I think you are all familiar with the fact that paper making was invented by the Chinese around 105 B.C., as close as we can figure it. But I do not think many of you realize what little basic progress has been made since that time. The first paper machine was not invented until 1790. It took us almost 1900 years before we improved on the technique of the Chinese. All early paper was made by hand and it was not until 1790 that we even changed this technique of making paper. Then, as often happens, the fellow who invented the machine never got credit or financial benefit out of it. His name was Louis Robert. If you ever get a chance, it would be interesting to read his patent because even in those days they were doing a little witch hunting. He inserted in his patent a false statement which he thought true at the time. He said he had developed a method of making a continuous sheet of paper without the use of fire or magic. As you get into the study of paper making, you find how wrong that statement is because we certainly use a lot of fire and magic in making a sheet of paper today. It is your job along with the rest of us in the industry, to take the magic out of paper making and bring it down to a known science.

The first machine, surprisingly enough, was what we now consider a form of Fourdrinier machine. I always thought that the cylinder machine was the simplest form for making paper but they started out the hard way. The first Fourdrinier machine actually was of a design around which the most modern machine is being built today. They ran their breast roll in a vat, with the Fourdrinier wire running around this roll in the stock and thus picking up the sheet on a continuous wire without using the present typical head box. Some of the most futuristic designs are based on this principle. Since 1790, we have made a great many mechanical strides in the art of making paper. However, they have all been based on very old principles.

By the way, this original Fourdrinier machine is still on exhibition at the University of Grenoble in France and once a year on the anniversary of the University they start it up and make paper on it. If you are ever over there, take a look at it.

Coming back to my early paper making experience, I would like to tell about an idea I had at that time. Once a month we met the management and presented a technical paper to the group. The more radical that paper could be the better the vice presidents liked it. I found out later that sometimes what the top brass liked, the production men did not appreciate. I presented a paper stating that it was amazing to me when I came into the mill to see a million dollars worth of equipment, using all the known arts and sciences, being run by highly trained crews, and all that came out on the other end was a simple sheet of paper. It seemed to me, I said, that

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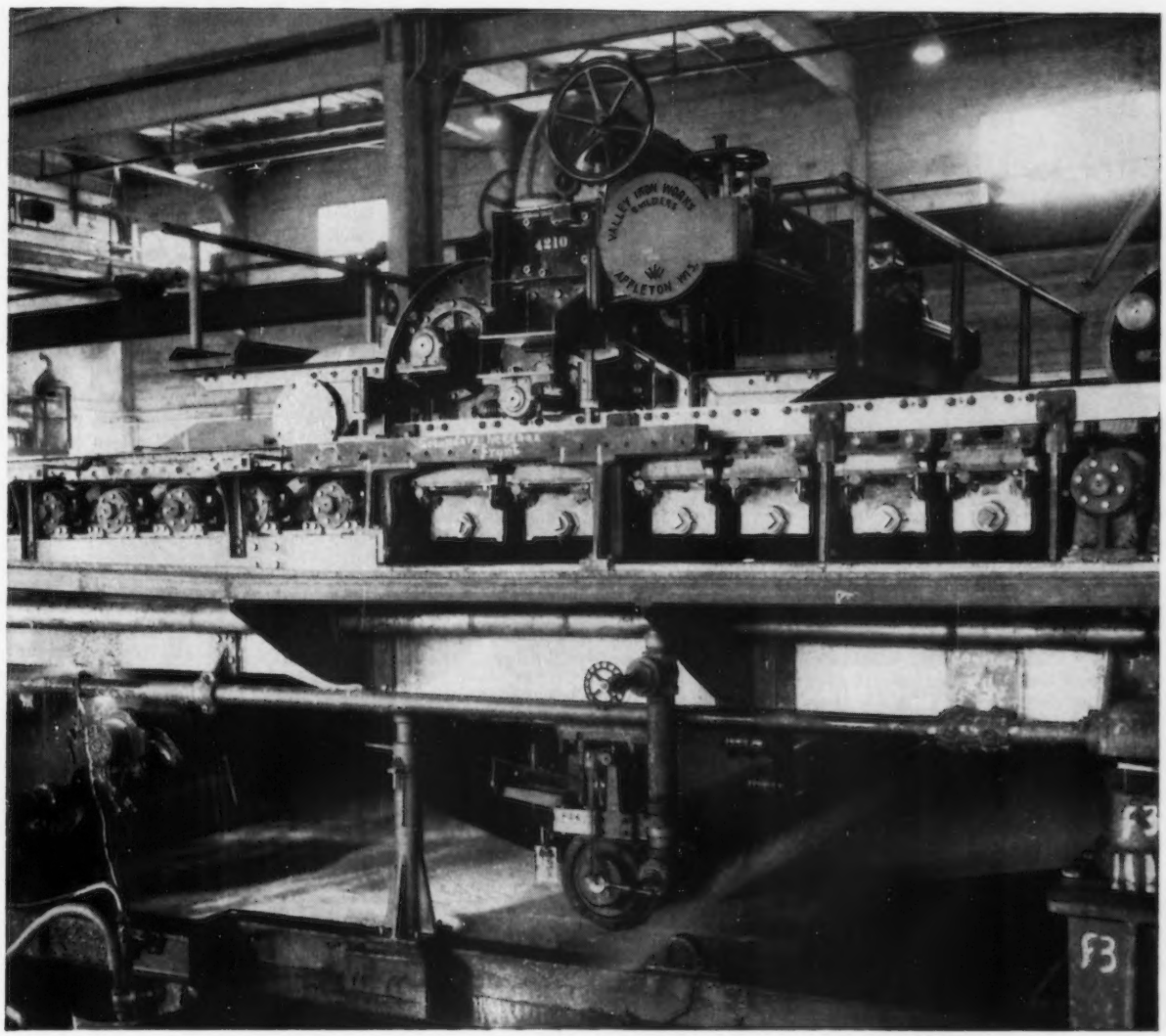

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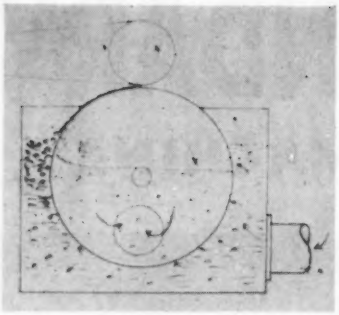

Figure 1

what the Chinese did not do in designing a paper machine, Rube Goldberg did. I was serious because it just did not seem right to me then, and it still does not now, that we put about 99.5 per cent of something in the wet end of the machine which does not exist in the final end product, namely water. All of this million dollars worth of equipment is used mainly for the purpose of getting rid of water. It caused most of the trouble. Some day, as I explained in this paper, they are going to find a method of changing this.

I said at that time that I thought we could learn a lot from the felt industry. About 98 per cent of the material going into a felt machine is material that is in the final product, and only about two per cent is water that they have to get rid of. They spray dry fibers in an air stream and deposit them on a dampened surface. According to the chemistry of cellulose fibers, this is more than enough moisture to bond fibers. Maybe you are taught what causes this bond but I am still confused. There are several theories which can be disputed because it has not been proven whether this bond is mechanical, chemical, electrical, or combinations thereof. The bond is not made primarily on the Fourdrinier. It is made in the presses where the dampened fibers are pressed together. The prime purpose of the Fourdrinier is to uniformly distribute the fibers in a water carrier so they can later be pressed into a sheet. I said, in that paper, someday we will find a way of depositing fibers on a continuous dampened surface, using a carrier other than water, and then peeling the sheet off that same surface as a dry finished product.

That is not in the near future but I think that if paper making had not been invented until 1930, we would probably be a lot further along than we are at the present time. We have too much background, too much Chinese outlook in the design. It is mostly our fault because we take old principles that we know have bugs in them, that are wrong and obsolete, and improve on these rather than starting off with new basic principles. No one has the nerve to completely revolutionize the art of making paper.

Cylinder Machines

I am going to concentrate primarily on the wet end of paper machines. I do not know too much about Fourdrinier or cylinder machines but I do know more about the Fourdrinier than I do the cylinder. However, in order not to neglect the cylinder machine completely, I have a series of Figures which show the development of the cylinder vat on a cylinder machine. There are a lot of other differences between a Fourdrinier and a cylinder machine but, basically, after the sheet is picked up, or formed, either on the cylinder mold or the Fourdrinier wire, the principles of pressing and drying are the same from there on.

I want to acknowledge these Figures. They were drawn up by "Doc" Cook, General Superintendent of Sweet Brothers. It is a small mill but he has done a wonderful job on making paper in that mill.

Figure 1. This is the cylinder vat and mold in its simplest form. I am sure you are familiar with it and I am just showing this to begin the series on the various cylinder molds.

They started out, of course, with no idea of approach flow to the vat. They just ran the stock into an open vat, turned a wire cylinder in it, picked up whatever stock they could in whatever condition they could and couched it off. That is the same principle as the old hand sheet. They created a pressure differential so the sheet would drain by the difference in level inside and outside the cylinder. The fibers went on, I am sure, in a very streaked way. At least, if they did not, we have done a lot of work on the rings, flow, and so forth, on modern vats and have spent a lot of money needlessly.

Figure 2. This is beginning to approach a vat that is in use at the present time, the uniflow vat. It is a cylinder travelling in the same direction as the stock. They have the cylinder ring designed theoretically so that the velocity in the outer ring is kept uniform. As the stock drains in, the pacsage is narrowed to maintain uniform flow. It has been found that if an overflow is not maintained at the exit of the flow, the consistency of the stock becomes very heavy and, since this is the last point where the stock contacts the sheet, stock is rolled off, streaks are formed, etc. They try to control this ring so that the variation in passage compensates for the amount of stock draining to the wire. The water drains through the wire and fibers are deposited on the mold. One of the things that they say about a cylinder machine is that you can make so many different products on it. Actually in my mind it is a very inflexible machine because as you vary the consistency of the stock or the types of fibers, the ring should change. There are vats on the market where you can control the ring, but they are in the minority.

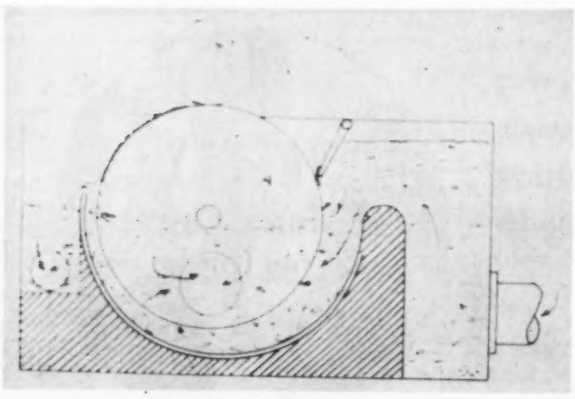

Figure 2

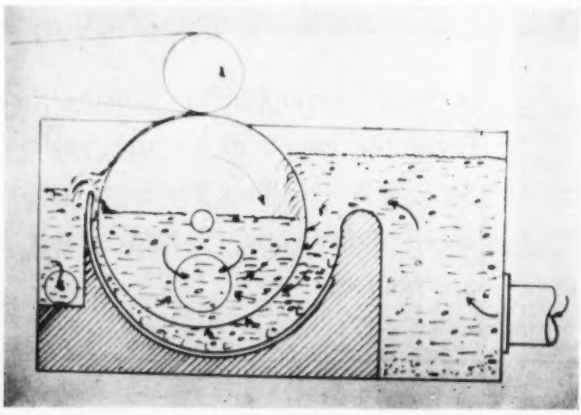

Figure 3

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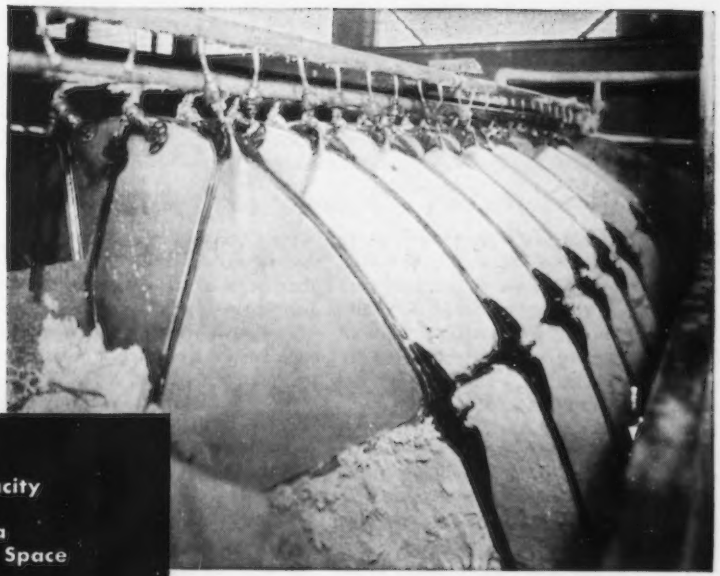

American Disc-Type Saveall recently installed in the Chester, Pa., mill of the Scott Paper Company. Note the water jets peeling off the sheet from individual sectors.

Looking into the future, many paper mills are likely to be confronted with a "space" problem. How about your mill? Are you planning to

a...speed up your paper machines
b...install additional or larger machines
c...operate with greater tonnages of slower stock
d...reduce stock losses

To carry out any one of these plans will involve handling greater volumes of white water which may be beyond the capacity of the largest single drum type Saveall. If floor space is no problem, you can make your choice between the Oliver Drum Type Saveall and the American Disc-Type Saveall. BUT, if extra floor space is either non-existent or set aside for other purposes, look into the merits of the American Saveall.

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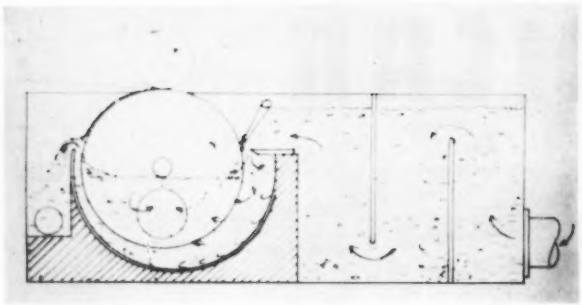

Figure 4

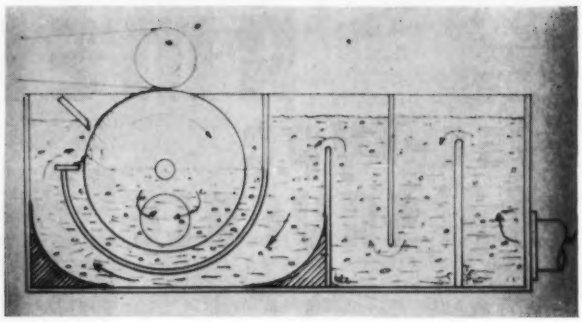

Figure 5

Figure 3. This is a modification of that in the previous figure. It is again a uniflow vat. One of the characteristics of a cylinder machine is what they call cylinder formation. Cylinder formation means it is very directional with very little cross direction strength. There have been all kinds of methods and apparatus used to try to overcome this weakness. Vibrators, mixers and everything else have been used in attempt to deposit fibers in a cross position. This slide shows one of the attempts. A top slice has been added to limit the area of approach of the stock to the wire thereby increasing the velocity of the approach flow. This gives a slight pressure entrance. If the fibers are agitated in this entrance by various means, including electrical vibrators, the pressure flow has a tendency to deposit an initial layer of these agitated fibers on the cylinder. This is again the uniflow with an overflow. But it shows one of the first attempts to get cross strength. Some mills get cross strength with this method and some do not.

These figures, by the way, outside of numbers *1* and *10*, are actual schematic drawings of vats that are in successful operation in the United States today.

Figure 4. It was soon discovered that the conditions of approach to a cylinder machine were just as important as they were on the Fourdrinier so they began to build various approach passages, one of which is shown here. Stock comes out of a pipe, through several vertical passes in an attempt to dampen it, until you get a quiet pond before the cylinder entrance. Now again they found in this mill with all their agitators, and so forth, that the fibers took the position more due to the flow of stock than to any mechanical agitation you could put in the flow. So they brought their top lip way down and put a little standing board on top of the approach so the velocity through there was several times the velocity of the wire going around. This whirled the stock and forced it onto the wire, thereby increasing the amount of sheet which was set on the first part of the cylinder.

Figure 5. This is a typical tissue, or light sheet, cylinder mold, where they do not require the full surface of the cylinder. The only reason for the diameter of the cylinder being as large as indicated is that centrifugal force limits the forming speed of the mold. Whatever force there is on the outside to put the layer of fibers on the surface, there is an opposing centrifugal force trying to throw the sheet off the surface. Of course, that force for any given speed is greater the smaller the diameter of the cylinder. On tissue cylinder this is a definite speed limitation.

A very small surface of the cylinder is used to form the sheet in the type of uniflow vat shown here. The stock does not contact the surface of the wire on the cylinder until it goes over the forming board which contacts the cylinder with a rubber strip, to prevent the stock from flowing back around the cylinder. A top slice has been added in this particular mill to increase the exit velocity of the stock. This tends to set the sheet and prevent it rolling back.

Figure 6. This vat is producing tissue in a mill at higher speeds than centrifugal forces would indicate. This 48 inch diameter cylinder has a theoretical top speed of about 450 feet per minute. At this point, the centrifugal force balances the drainage force and the weight of the stock. However, this machine is running about 750 feet per minute. A felt plasters the sheet on the wire and holds it there as it comes out of the surface of the pond. I have never seen this machine run, but I have seen some of their products. I cannot understand why they do not get terriffic crushing even though they use a very special open felt.

Figure 7. This shows an actual head box with the fibers flowing onto a cylinder vat very similar to a head box with fibers flowing onto a suction breast roll on a Fourdrinier. This is a vat that is actually in operation at the present time.

Figure 8. This shows a counterflow vat. Its typical use is in heavy board machines. I do not understand the principle of it. The stock is flowed one way and washed through the screen another way. I do not think it is logical.

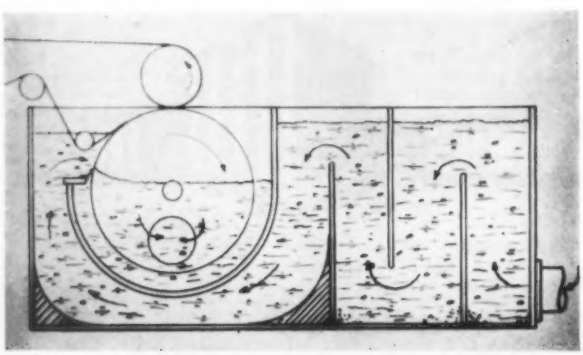

Figure 6

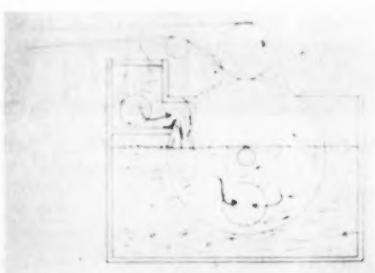

Figure 7

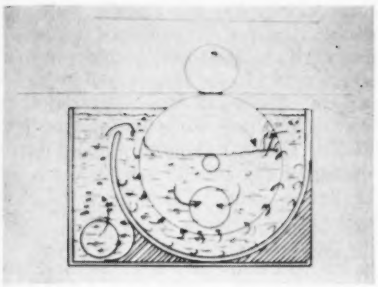

Figure 8

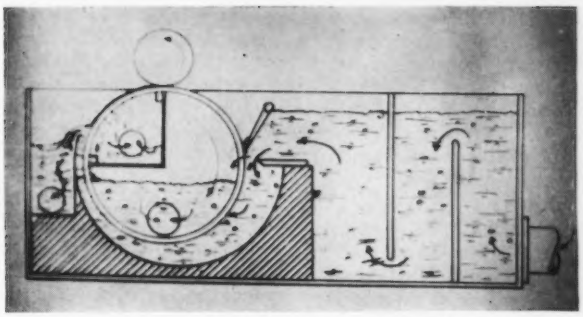

Figure 9

Eastman Kodak has done a lot of research on counterflow cylinder vats. They have built vats with plexiglass sides and used high speed photography to record the results. These results showed that the sheet forming, washing off, and forming again in its normal flow around the counterflow vat. However, there are a lot of machines built and running successfully on the principle of the counterflow where the stock flows one way with the cylinder running the opposite direction. They say it gives a better surface because the last part that goes on the surface is the best mixed stock.

Figure 9. Here is one of the most modern cylinder molds in operation at the present time, where they actually use a vacuum. There is a critical speed on a machine where centrifugal force has a tendency to throw the mat off the cylinder and distort the fibers as the water drains down over the surface, giving uni-directional formation. This vacuum quadrant was added to fix the sheet at the critical area to prevent this. It is very simple as shown in schematic view but actually requires a rather expensive form of construction. Most molds are built with spokes and rings. This mold has to be built more or less like a vacum press roll. In other words, there is no inner construction. The sheet is formed in the normal way until the mat starts to leave the surface of the stock. At this point, vacuum is applied which sucks water from the sheet and holds it on the cylinder against centrifugal action. This sets the formation and prevents the runback of water over the surface which, in my opinion, is one of the main reasons for uni-directional strength.

I understand there is a mold of this type now being designed for a speed of 900 feet per minute but, as far as I know, this type has never run faster than 750 feet per minute.

Figure 10. A gentleman by the name of Hilliard ("Doc") Cook decided that machine builders were building their suction vats the wrong way. Why did they put their quadrant where the sheet had already been formed? In the previous slide, the sheet was formed around three-fourths of the circle in the usual manner and vacuum was used to hold the sheet in the last quadrant after it had been formed. *Figure 10* shows how he proposed to combine the head box, as shown in *Figure 7,* to get pressure formation and then use the same vacuum set up as shown on *Figure 9* to hold the sheet.

It is interesting to note here that one of the most modern, and fastest, Fourdriniers in operation today is built on this principle of pressure formation on a vacuum breast roll.

In the theoretical cylinder mold shown in this slide the forming quadrant is under vacuum while the rest of the circle is open to atmospheric pressure. In the open area, cleaning showers clean the wire and this water is caught in the surrounding drip pan. The water drained from the stock is all taken out the vacuum quadrant. The vacuum should eliminate speed limitation to centrifugal action and permit high speed operation on light sheets.

Fourdrinier Machines

There is a Fourdrinier machine built with a suction breast roll, and a pressure slice leading up to that breast roll, forcing the sheet onto the wire similar to that shown on the cylinder machine in *Figure 10.* This runs about 2750 feet per minute in production and, amazingly enough, I understand that it only has a 40 foot wire and that the sheet is completely formed in about 40 inches from the edge of the slice lip. It is amazing that on a machine running close to 3000 feet per minute a sheet can be formed in about 40 inches after it leaves the slice lip. A suction breast roll is not a new idea but it is the first one that has been run successfully.

I want to concentrate on the Fourdrinier machine which, of course, is the oldest in principle and also the most modern type of machine. They are beginning to use this machine on all types of paper now and it is the one that we build most often.

Figure 11 The next set of slides deals with the development of the head-box. This slide shows a typical four-pass, old style head-box. The principle of paper making until rather recently was to bring the stock in and wear it out by passing it through a multiplicity of passes and finally obtaining a very quiet pond, before it went onto the wires. They thought this gave them a uniform distribution of fibers.

Recent investigations, utilizing experimental work on plexiglass headboxes have brought out interesting facts about stock in the head-box of the Fourdrinier. First of all, the condition of the stock coming onto the wire has more to do with the actual sheet formation than the travel on the wire. As on all these high speed machines, if the sheet is formed 40 inches away from this slice lip the Fourdrinier itself has very little to do with the formation of the sheet. With the type of head-box shown in *Figure 11,* the sheet came out in all kinds of conditions. Here the job of the Fourdrinier was to overcome the faults of the head-box. Now another way is being tried to get the head-box to bring the stock out in the right condition so that the Fourdrinier has, as its main job, the removal of water and not the formation of the sheet.

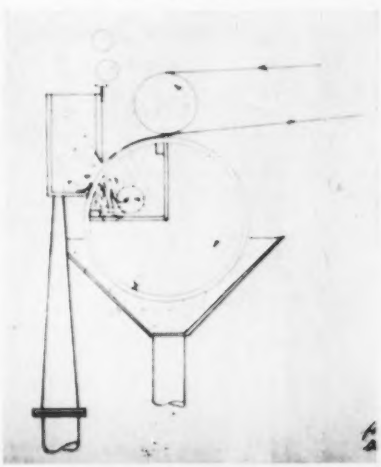

Figure 10

At the entrance pipes into the head-box the water and fibers are in the best suspension of any place on the machine. They are completely, independently separated due to the agitation and processing of the refining equipment.

From this point, in this old type of head-box, the stock may be in any condition when it arrives at the slice and it is usually in clusters. The idea here was to flow the stock through long passes and slow it down so that any cross flows would have a tendency to quiet down and form a uniform flow to the machine. The purpose of a head-box is to take a restricted flow from the pipe entrance and spread it out to maybe 300 inches in width and still maintain a uniform fiber suspension and a uniform flow in the machine direction. This head-box could not do this because the flows were so slow they allowed flocculation of fibers, eddy currents, and pockets for slime formation.

Figure 12. This is a modern type of head-box working on the principle of controlled agitation in the box. We believe that the stock is in the best condition possible at the point of entrance. If we could only get it distributed across the width of the machine in this same suspension, the purpose of the box would be fulfilled. We try to get the sheet on the wire as quickly as possible from the point of entrance to the slice lip. The box shown here is a high speed head-box. The stock enters the box through a multiplicity of pipes which are spaced about every 30 inches. These pipes reduce in vertical dimension, and widen in a horizontal direction, to form a fan approach into what we call an explosion chamber. As the stock enters this explosion chamber at high velocity, it tends to swirl. The exit of the chamber is necked-down so that it is easier for the stock to flow in cross direction than vertically, as stock will always flow in the path of least resistance.

Another condition that is accepted in hydraulics is that any restricted orifice will affect high velocity more than slow velocity. Hence, the restricting orifice out of this explosion chamber tends to slow down the high velocity flows more than it does the slow velocity. As the stock comes out of the chamber, it will tend to even out. Right at the top of this venturi exit, we put a distributor roll to agitate the stock, and again, restrict the flow, as the area of openings through the distributor roll is only about fifty percent of the area that ii takes up in the flow passage. The velocity of the stock at this point across the roll, therefore, is about twice what it is at the approach to the roll or at the exit from the roll. Again the high velocities will have a tendency to slow down more than the low velocities.

The queer looking objects in the vertical passes are what we call tear drop agitator. They have the same purpose as distributor rolls but have the added advantage of being adjustable. They can be spaced in different positions in either of these passages. This adjustment is needed because all stock or fiber has a time of flocculation depending not only upon the natural fiber but upon the treatment the fiber has had, the amount of hydration, and so forth. We do not know exactly

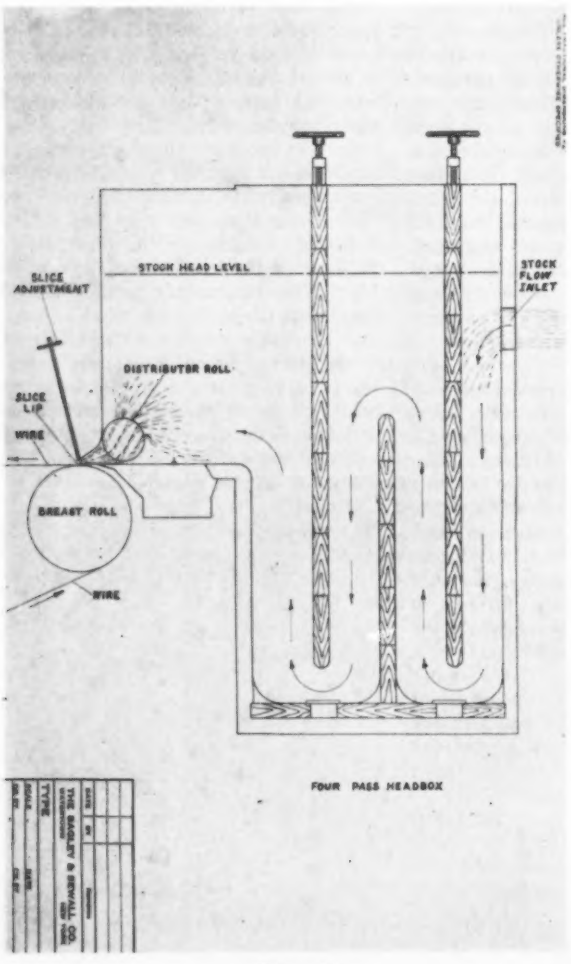

Figure 11

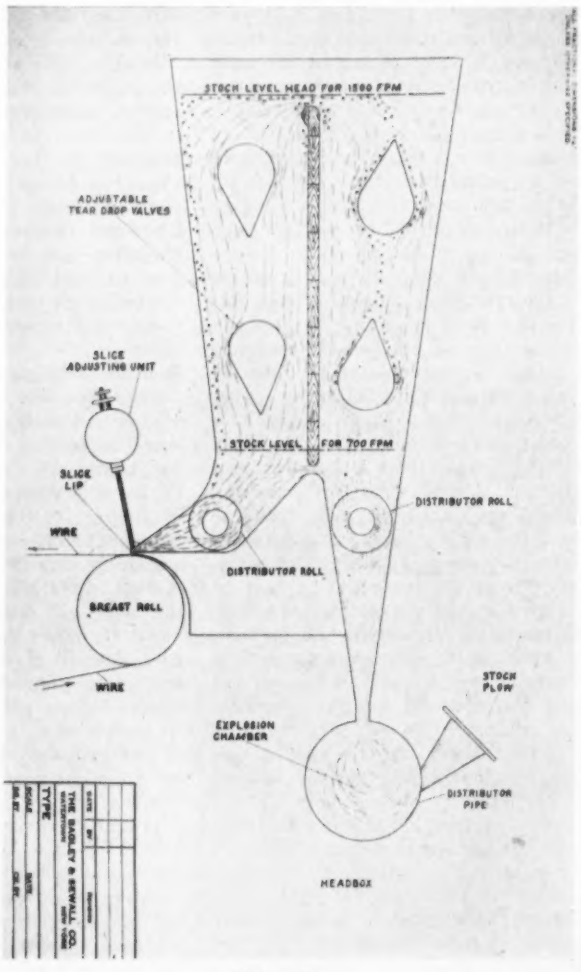

Figure 12

why, at least I have been told we do not know why, fibers tend to come together and form flocks. We do know that if fibers are left in a suspended solution for any length of time, they will come together just like magnets and grab into a multiplicity of fibers or flocks.

We check this in our head-boxes with what we call our blue glass method. A light film of completely agitated stock is poured onto a blue glass which is then agitated just enough to keep the fibers off the bottom. Using a stop watch, the time of flocculation is checked beginning with the time that the stock is put onto the blue glass, until those fibers suddenly grab. This may run from thre to five seconds. Flocculation will occur both in a quiescent flow or in a fast flow if you do not change velocity. In other words, when stock is placed in a fast flow, and left in that fast flow without changing the velocity or the direction of the velocity for a period of six seconds, the stock will coagulate or flocculate. When the relative position of the fibers is not disturbed they have some sort of electromagnetic attraction for each other.

When you get these fibers in flocks it is difficult to get them apart. Flocks cause bad formation. These adjustable tear drops are used so that the time of flow between them is less than the coagulation period of the stock. For different stocks and different flow velocities this adjustment is needed.

We found another interesting thing about these tear drops, which are hydraulically designed. In fact, the man that designed them spent most of his time during the war on aerodynamics. The tear drop has a de-aerating effect on the stock and you will find bubbles of air being kicked out of the stock coming off the points of these tear drops. Of course, the principle of getting rid of entrapped or absorbed air on the fibers is to get them in bubbles big enough so that when they come to the surface you can break them up and get rid of them. *Figure 12* shows schematically how these air bubbles tend to flow. Air bubbles tend to float to the surface but if you do not get rid of them on this surface they will tend to go down the front side of the head-box wall and come out on top of the stock.

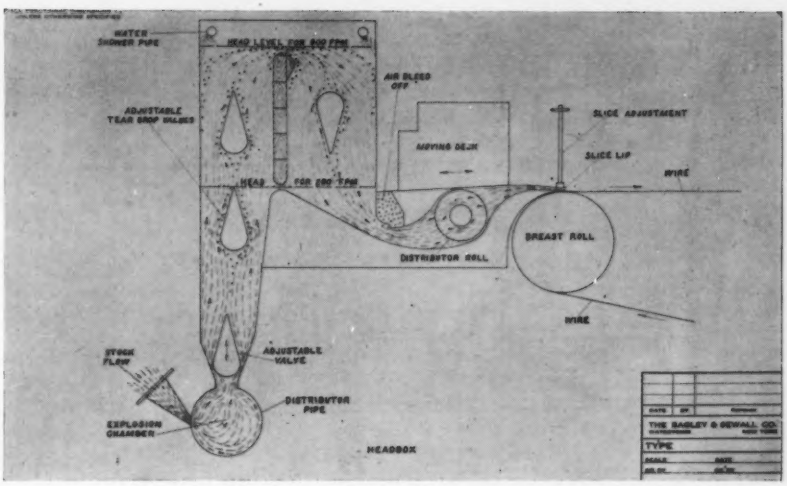

Figure 13

We have done another thing with this high speed head-box which is not shown here. This is what we call a warping beam. On these high speed head-boxes, there is a weak point of construction at the beginning of the curved lip. The vertical wall can be built up so it is very rigid with big construction beams but the flexible slice lip, of necessity, has to be of light construction. Although, the lip can be stabilized at the beginning and end of the curve, a vibration, actually causing bad formation on the wire, will develop in this curve on a wide machine. From this big warping beam, we not only support the lip adjusting screws but also an extra set of support screws to the mid point of the curve. Normally these stabilizing screws are adjusted only once to give a straight stable line but they can be adjusted as needed to even out flows.

I have noticed another thing that we are going to use more and more in our head-box designs. We are using what originally was called, I believe, a Van de Carr hump. On high speed boxes it was found advantageous to begin a nozzling effect some distance before the actual lip in order to have good flow through this lip. The lump starts this nozzle effect and a distributor roll is placed as close to the lip as possible to give the stock final agitation before it is released onto the wire.

Figure 14. This is another design, a modern design, of a head-box which we have developed to take care of a wide range of speeds. A wide range is especially important not only in this country but in Europe where they do not have specially one purpose ma-

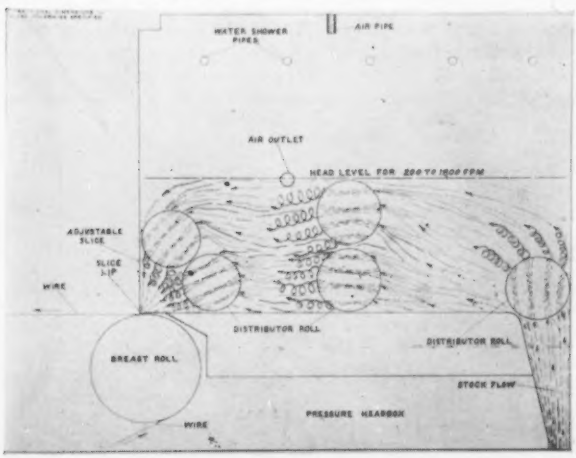

Figure 14

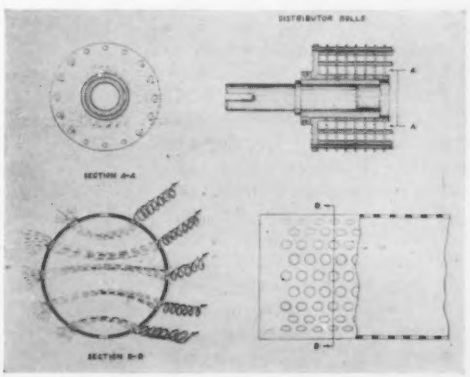

Figure 15

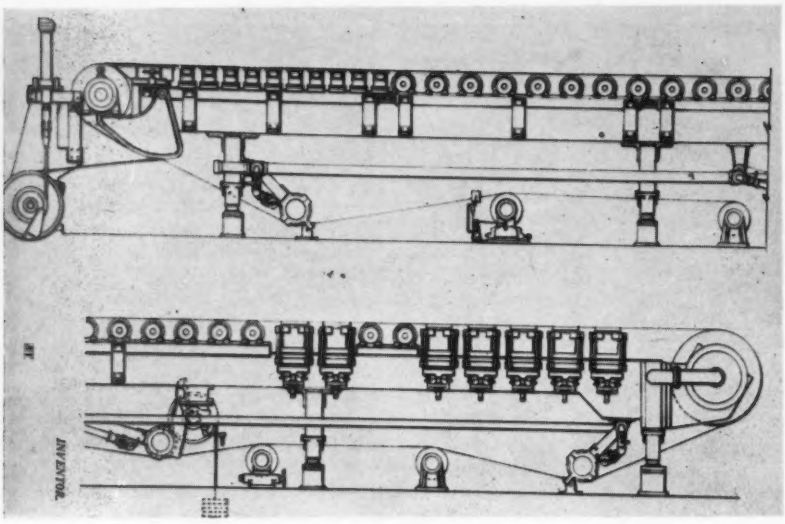

Figure 16

chines as we do. They have one machine that has to make everything from tissue to board on short runs of all kinds of paper because their market for any one brand is not as great as it is in this country.

This machine shows a head-box design for a speed range of from 200 to 800 feet per minute. At 200 feet per minute the theoretical head is only about one and three fourths inches of stock above the wire. In a typical head-box construction, the distributor roll is actually ten to fourteen inches in diameter, which means that if there is flat approach to the bottom slice through the distributor roll to the wire only a couple inches of the distribtuor roll is under water or stock. The rest is exposed. It has a tendency to pick up fibers, carry them around and form lumps. Also on a flexible lip there is a dry line in the curve because the stock is down below the curve. Clusters of fibers and slime form here break off and cause trouble on the wire. The design shown in *Figure 13* is based on the same principle as the first head-box. Stock flows into an explosion chamber and tear drops are used as required to break up the flocculation. However, the approach of this head-box is below the level of the wire, so whether you are running low speed or high speed the approach stays completely submerged and there are no dry lines.

Another feature is shown in this box. Slow speed machine stocks are usually heavily loaded, heavily sized and often colored. This type of stock traps much more air than the straight fiber mixtures. Dots in this diagram indicates the passage of the entrapped air in the flow. As much air is brought together as possible and removed at the top with showers. In the last down flow, the stock is still richest in air along the front wall of the head-box. At the beginning of the necked-down flow to the slice there is a bleed off slice opening which bleeds off a controlled amount of this air rich stock for recirculation. This reduces to a minimum the amount of air entrapped in the approach flow which can get onto the wire and cause trouble.

You will note that *Figure 13* shows a tear drop restriction at the exit of the explosion chamber. This is actually an adjustable valve which can be brought down to restrict the passage in slow speeds or raised to open the passage for high speeds. The adjustment is controlled to insure stock flowing across the machine in the explosion chamber before it starts vertically through the box.

(Class question—"Does the water go under the dam as well as over the top?") We have found we could not make a perfect joint at the bottom of the dam. If we do not allow a flush of water to go through the bottom joint, stock and slime accumulate there and break off. We keep a flow going through this passage continuously to keep it washed clear.

(Class question—"At a lower speed do you just remove one of the top boards in the dam?") At a lower speed one of the intermediate boards is removed and the top one is kept on. A streamline bulge is put on the top board because on a typical dam which has a square on the top you get what we would call cavitation in a turbine. Stock begins to whirl around that sharp edge and may form balls of stock before breaking back into the flow. The top board in *Figure 14* has half a tear drop on it so the stock will flow over the top and continue to flow.

Figure 14. This is the famous pressure head-box. As the speed of machines is increased to 2500 feet per minute and above, the standard open head-box becomes so bulky, it is difficult to design the structure. Pressurized head-boxes have been designed to keep the height of the stock uniform by creating a pressure or vacuum above its surface, thereby obtaining the necessary head for a desired speed by means other than depth of pond. The stock comes in through a flow distributor, through a distributor roll, and then goes straight across what is really a rectangular box. Distributor rolls are put in the horizontal flow to break up flocculation and distribute the stock before it reaches the slice.

The box shows about 32 inch head of stock which would be correct for a speed of 400 to 500 feet per minute. When running at 2000 feet per minute, air pressure is added in the chamber above the stock to create the necessary pressure at the slice lip for proper flow. A constant volume of air is pumped into the chamber at all times. It does not really matter what the pressure of this air is as long as it is above the pressure required for top speed. An outlet is shown at the stock level and is of such an area that when it is about 60 percent exposed, it will discharge air as fast as it is pumped

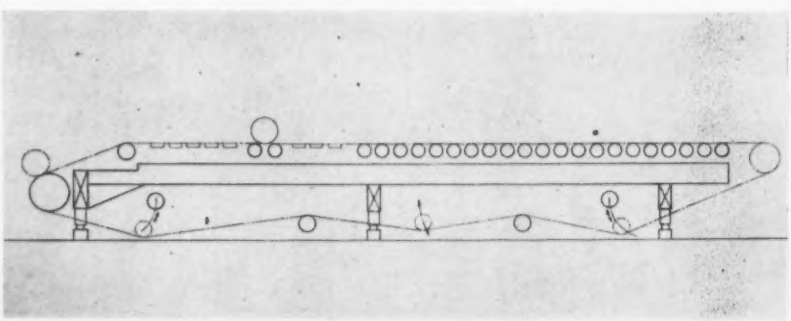

Figure 17

in. A certain amount of stock and air is being constantly pumped into the box. If the air pressure in the chamber is not great enough to force the stock out of the slice as fast as it is being pumped in, the level of the stock tends to rise covering part of the air exhaust opening. When this happens, air can not get out as fast as it is pumped in and pressure is built up. As air pressure builds up, the level of the stock is forced down until it balances. If the level of the stock lowers, more of this outlet pipe is exposed and the air escapes faster than it is coming in, thereby reducing the pressure above the stock and the level again will rise until it balances.

Vacuum would be used in the chamber whenever machine speeds got below the allowable 32 inch stock level of this box. The vacuum reduces the pressure over the stock below atmospheric pressure thereby giving the equivalent of a head lower than 32 inches. To accomplish this, the pump connections are reversed so that the former air pressure pump now becomes a vacuum pump, pulling vacuum through an outlet. A bleeder valve is connected on the opening marked air pipe. This valve is regulated until a visual check through a plexiglass section of the outlet pipe shows a mixture of both air and water flowing through. If the air bleeding into the box is too small, the water level rises in the box, thereby closing the outlet and only stock will be withdrawn. If too much air is bled into the box, the vacuum is reduced, the stock level falls and only air will be pulled off. Visual observation and hand control on the bleeder valve keeps this air-stock pull in balance.

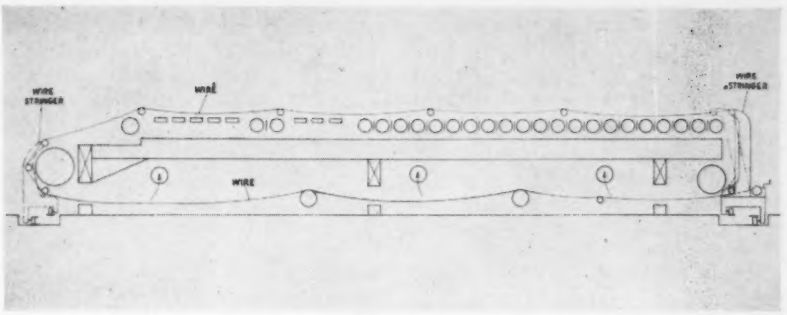

Figure 18

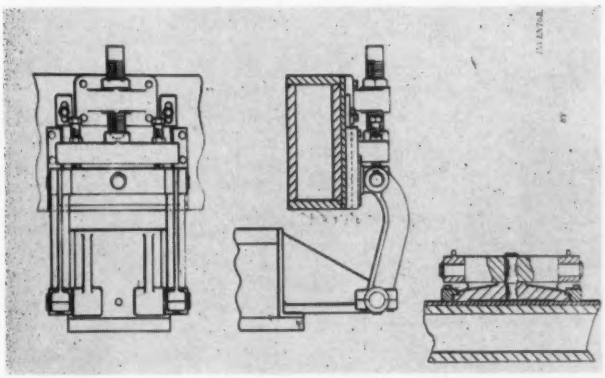

Figure 19

A big difference in principle between this and the standard box is in the time of flow through the boxes. In an open box the time of flow through the passes can be regulated by raising or lowering the dam thereby controlling the stock for a long enough

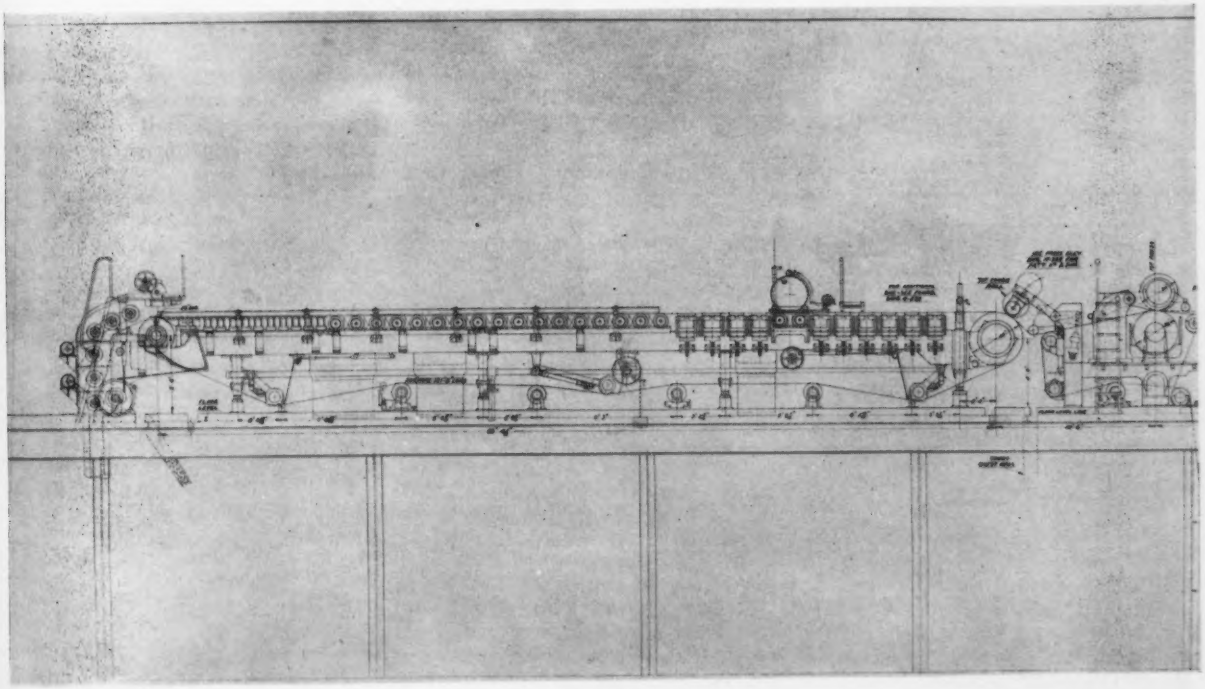

Figure 20

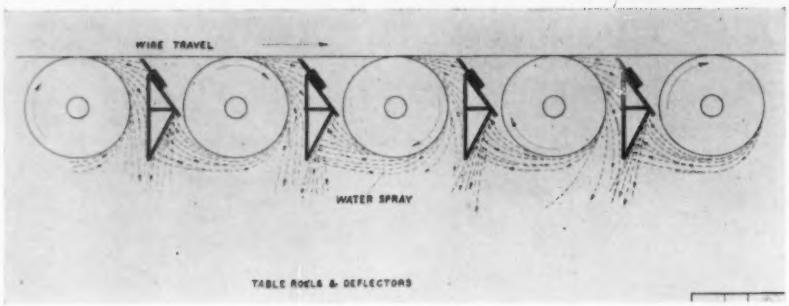

Figure 21

time to even out cross flows and still prevent flocculation. In a pressure box, the cross section and distance of flow through the box is the same for all speeds.

Figure 15. There has been an interesting development recently in distributor rolls. Section BB shows a typical perforated distributor roll which you all recognize. This type of roll has caused certain problems especially in the South where they use very long fibers. As the stock flows through the holes, from an open chamber, it has a tendency to spiral. This will actually work the long fibers into worms which are visible in the sheet. Also on some of the lighter sheets, the staggered holes in the roll surface will snake the flow enough to actually show up in the finished sheet.

The roll shown in Section AA was developed to overcome these two defects of the typical perforated distributor rolls.

The new roll is made up of a series of discs about one-sixteenth of an inch thick held together on a center pipe with spacers. Around the periphery of these discs is a series of one quarter inch rod. This construction does several things. It gives the same agitation as the perforated roll because the change in area as the stock passes through the roll, speeds up and slows down the flow. In addition, the series of parallel discs tend to parallel out all cross flows. When used just before the slice opening, they give the same effect as fiddles without the danger of fiber collection. Also the rods on the periphery chop through the stock as the roll rotates and tumbles the fibers. This effect can actually be noted in the change in cross directional strength in the sheet as the position or speed of the roll is varied.

Figure 16. This is an actual photograph of an engineering drawing on a new type of Fourdrinier which is about to start up in the South. It has a 230 inch wire, 125 fet long and is built to run 2200 feet per minute on kraft bag paper. The design is a permanent canti-

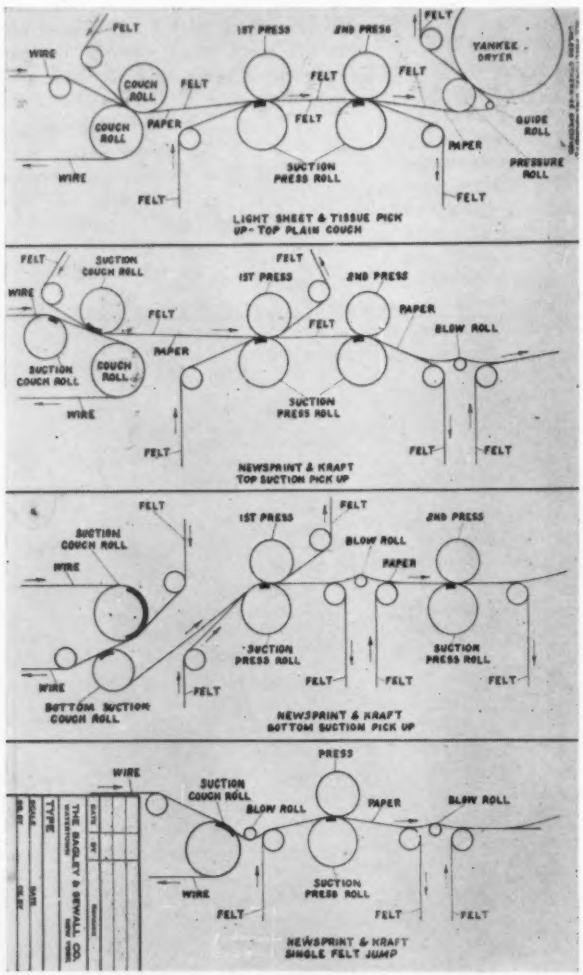

Figure 23

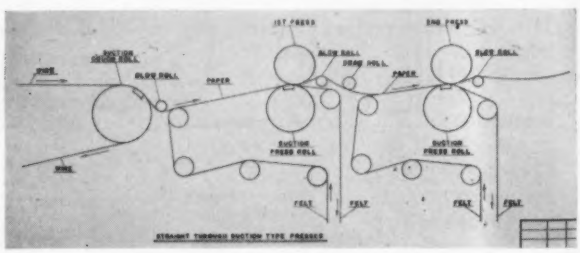

Figure 22

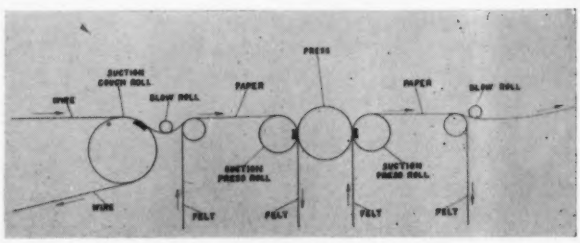

Figure 24

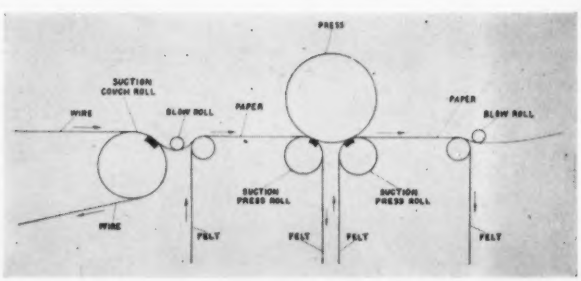

Figure 25

lever type and weighs about 300,000 pounds.

There are many methods of preparing a Fourdrinier to receive a new wire. The most common method is to move the entire 300,000 pounds of precision equipment about 30 feet into the aisle, string a 1200 pound wire in the pit and move the heavy mass of equipment back into the wire loop.

In the machine shown in *Figure 16,* the 300,000 pound Fourdrinier is permanently cantilevered in its running position. The wire can be strung in the aisle while the machine is still running.

The structural design of this Fourdrinier consists of two Fourdrinier beams supported on three permanently cantilevered cross support beams. The couch roll is mounted on one end of the Fourdrinier beams and the breast roll is pivoted on the other ends. Of course all top structure is mounted on top of the Fourdrinier beams and the inside wire return rolls are pivot mounted from the underside of the beams. In other words, this is a self supporting unit structure.

Figures 17 and 18. To open the front of the Fourdrinier to receive a new wire, the procedure is indicated in *Figures 17 and 18.* The three inside wire rolls are swung up and the breast roll is swung down hydraulically. The three cantilever beams are supported on removable spacer blocks resting on hydraulic jacks. To remove these spacer blocks, thereby opening up the front side, the hydraulic jacks are raised about one-sixteenth of an inch which takes the weight off two inch spacer horeshoes. The horseshoes are removed and the jacks lowered. The cantilever beams are prestressed to allow about one-half inch sag below the running level when entirely supported by their permanent cantilevers. Since a two inch spacer horseshoe had been removed, the half inch sag still gives plenty of clearance for the removal of the spacer blocks and the Fourdrinier ends up as indicated in *Figure 18.*

Another rather unique feature of this machine is the method of stringing the wire. We string a tight wire between two end pedestals without any clumsy tie members between these pedestals. The actual stringing is done with a slack wire over support poles in the aisle. The breast roll pedestal is pivoted so it can be swung toward the couch roll during the stringing operation and then cranked to a vertical position. This makes the wire tight enough that the wire can be moved across the Fourdrinier using only these end poles on the pedestals.

Figure 19. This is an enlarged view of the engineering drawing shown in *Figure 16,* and shows more clearly the construction of this Fourdrinier as previously discussed. Perhaps you can also see one of the new features built into this design.

Machine tenders never seem to have enough pressure available for their wire showers. This is especially true in the first shower which is supposed to wash the sheet off the wire when there is a break and the sheet follows around the couch roll. Pressures up to 150 pounds have been used and still the sheet, or at least many fibers, tend to stick to the wire and dirty it up. On a fast moving fine mesh wire, most of the pressure effect is dissipated on the wire itself before it strikes the fibers. In this design, we have put a low pressure high volume shower in the approach nip of the first inside return roll. The water tends to lay in the nip between the roll and the wire and is mechanically forced through the mesh at a much higher pressure than could be obtained by a direct shower.

Figure 20. This slide shows a new method of supporting the heavy, wide, oscillating suction boxes on this machine. The boxes are supported on double rocking arms which have an adjusting screw for vertical adjustment plus leveling screws. This construction gives a very stable mounting with very low frictional resistance to oscillation.

Figure 21. This figure shows a typical deflector used on this wide, high speed Fourdrinier. Here the design problem was not only stability but also a two way doctoring of the water fling. A triangle is one of the strongest forms of construction so we used it. Fast running, big table rolls tend to carry water around the up-running side of the roll and fling water back into the wire. Hence, if you will note, this deflector doctors water on both sides of the roll at the most effective points.

The Press Section

Figure 22. This next series of figures is on the press section. Unfortunately time permits only a very brief covering of this subject as shown on these schematic views.

Figure 22 shows a typical straight through press that is common in all high speed machines such as newsprint or kraft. The slide shows a jump pass from the Fourdrinier suction couch to the felts, typical double suction presses with the blow rolls and the draw rolls. The blow roll is used to take the sheet off the felt after passing through the press and let it equalize before the draw roll plasters it down on the felt of the next press. All of these rolls are usually adjustable up or down.

Figure 23. This slide shows the four typical arrangements of a press section. The top view shows a standard double felt with a top couch pickup used on light weight tissues. Here a pickup felt running between the top and bottom couch picks the sheet off the wire, carries it through the two suction couches and transfers it to the Yankee Dryer.

The second view down shows a new type of pickup that has been developed for high speed newsprint machines. One of the limitations on the speed of a newsprint machine is the sheet transfer between the couch and the press. The chemical fiber of the newsprint furnish has been increased continuously to try to make the sheet strong enough for an open jump. The tissue type of pickup cannot be used on the relatively heavy newsprint because there is a tendency to crush on a hard nip. Here a suction pickup roll picks up the sheet off the wire on a soft nip between a primary and secondary couch.

The third view down is a variation of the suction pickup that has been used in Europe. It seems even more logical than the upside down suction pickup shown above in that the suction transfer is down with gravity rather than against it and the wider wrap of the sheet around th suction couch makes the couch more effective.

The bottom view shows the same arrangement as explained under *Figure 22.*

Figure 24. This is a famous dual press. Just in passing, I will say it is now obsolete. It was a great idea but it did not work. The problem was to get crowns on all three rolls that would work under variable pressures. The next figure shows a variation of the dual press which works much better.

Figure 25. This is the press that is taking the place of the dual press and is called the cloverleaf press. The top roll is a relatively large diameter granite roll. The two suction press rolls contact it similar to a pressure roll on a Yankee. The pressure nips here are approaching the vertical nip of regular presses. Horizontal pressure rolls, as found in the dual press, tend to buckle up or down under increased pressure and therefore are not as stable, or as easy to crown, as the vertical roll.

It is the consensus of opinion that rf there is space, the best operating presses in the world are still single presses which you can control as independent members. Whenever three rolls are combined there is apt to be

trouble. The only excuse for either the dual or cloverleaf press is the need for more press capacity with a space limitation that prevents the use of single presses.

Conclusion

It is not presumed that all modifications of paper machines have been described. I hope, however, that a brief discussion of some features of botn cylinder and Fourdrinier machines has indicated some of the problems in paper making and emphasized the importance of machine design.

Fourdrinier Paper Machines—Dry End

Richard Estabrook

University of Maine 1936; worked on paper machines at S. D. Warren Co., Cumberland Mills, Me. 1936-1940; Assistant to Paper Division Manager, Brown Co., Berlin, N. H. 1940-1944; Mill Superintendent Johnson & Johnson, New Brunswick, N. J. 1944-1946; at present Development Engineer, St. Regis Paper Co., Bucksport, Me.

Introduction

There are two basic types of machines used in the manufacture of paper. The fourdrinier machine invented by Louis Robert in France in 1799 and later commercialized in England by the Fourdrinier brothers, and the cylinder machine invented by John Dickinson of Germantown, Pa., in 1809. Various modifications of the fourdrinier have been developed through the years for special purposes such as the yankee cylinder for glazed papers, the Harper fourdrinier for tissue papers, and the combination fourdrinier and cylinder machine for duplex papers.

We will, for the purpose of this discussion, limit ourselves to a consideration of the ordinary fourdrinier as exemplified by our two 231 inch machines at Bucksport which are relatively modern. We will also limit ourselves to those sections of the machine beginning with the smoothing presses and ending in the finishing room. Specifically, the article will cover the smoothing presses, dryer sections (including air handling and economizers), machine calenders, reels, and winders.

Smoothing Press Section

The smoothing press section consists of a rubber roll in the top position with a chrome roll underneath it. The paper is led directly through and between these two rolls. The purpose of it is to smooth the paper at a time when it is in the best condition to receive an impression. It can be seen from *Figure 1* that the chrome roll contacts the paper on the wire side which helps to eliminate the impression of the wire and makes the two surfaces more nearly equal. It is also believed that the smoothness achieved allows a closer contact between dryers and paper and thus promotes more efficient drying. Pressure on these rolls is applied by compound leverage.

Dryer Section

It is an accepted fact that every effort should be made to remove as much water as possible on the wet end of any paper machine, since the mechanical removal of water is the cheapest method. On our number 1 machine, for example, I estimate the cost of steam per ton of water exaporated to be $3.70 as compared to $0.50 per ton of water removed by wet felts. Although these costs do not represent an accurate comparison, I believe that they are indicative of the difference in cost between drying by steam and by mechanical removal of water.

As we all know, mechanical removal of water is limited and there still remains a large volume of water that must be eliminated from the sheet by the dryer section. As an example of this amount of water, we will assume a 40 per cent B. D. sheet entering the dryer section and a moisture content of 6 per cent in the dried paper. This is equivalent to about 1.3 tons of water to be evaporated in the dryer section per ton of paper. With poor conditions at the presses it may reach twice the weight of paper, or 2 tons of water per ton of paper. In any event, the amount of water that must be removed by dryers is tremendous and its efficient removal is of prime importance.

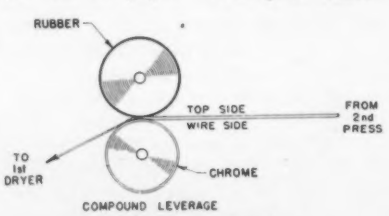

Figure 1—Smoothing Press

Let us consider the Bucksport fourdriniers so that we can obtain a general knowledge of their drying equipment.

A *Dryer Rolls*—The dryer sections of these paper machines are each equipped with 48 steam dryers. The dryers are of conventional design and the cylinders are of cast iron, turned perfectly true on the surface and polished. Dryer castings must be as near perfect as possible, since the presence of sand holes and other defects are dangerous due to the steam pressures and periferal speeds to which the cylinders are subjected. Dryer cylinders should be bored so that the shell is of uniform thickness throughout circumference and length. Dryers not bored in a uniform manner may give trouble because of lack of balance and will undoubtedly give a variation in drying effect because of differences in wall thickness at different points. The factor of balance is particularly important on high speed machines for obvious reasons. The cylinder surfaces should be highly polished and free from tool marks and blemishes since both would have an adverse effect on sheet finish.

B. *Dryer Clothing*—Each machine is equipped with the necessary felt carrying, stretch, and guide rolls. On any machine it is, of course, desirable that all of the dryers and rolls over

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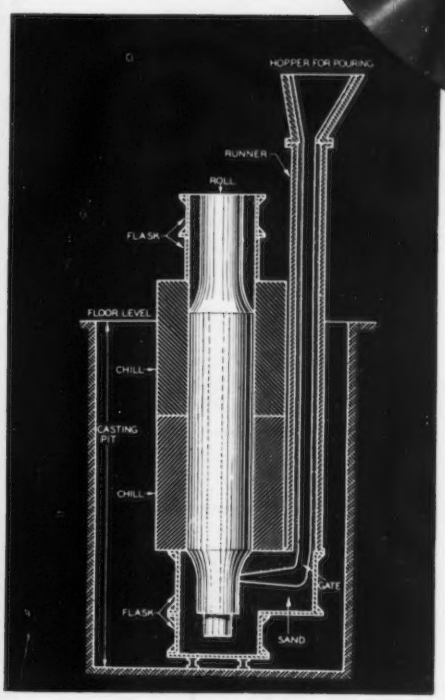

The body of a chilled-iron roll is formed by pouring molten metal into an iron mold or chill. Iron being a good conductor of heat, cooling is rapid, causing the surface of the roll body to "chill" and harden. The body of the roll below the chilled surface cools slowly, forming a gray iron structure which gives strength to the roll.

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which the felts travel be absolutely true, level and in line. It should be mentioned that the tension to which these felts are subjected is a very important factor in drying, felts that are too loose being as objectionable from a paper quality standpoint as those that are too tight.

C. *Steam Supply and Condensate Removal*—Each of the 48 dryers mentioned above is connected to the steam supply and condensate return system. These dryers are each equipped with siphons for condensate pickup. The dryers must be piped in such a manner that the sheet of moist paper will not be scalded as it starts through the dryers. This is done by having the wet end dryers somewhat cooler than those further along in the series thus allowing the sheet temperature to rise gradually. Searing the sheet as it enters the dryers would give rise to cockles, picks and other troubles and must be avoided.

The piping arrangement on our number 1 machine, shown in *Figure 2* will illustrate how we accomplish this purpose.

D. *Temperature Control*—For automatically controlling the volume of steam admitted to the dry end section, and indirectly the remaining sections, we use an indicating dryer. The indicating dryer, shown in *Figure 3*, is one of the dryers in the dry-end section. It is supplied with steam independent of the rest of the system. This steam first passes through a control valve which automatically maintains the pressure inside of the indicating dryer. It then goes through a flow tube which continuously measures the flow to this dryer. If the sheet passing over this dryer becomes damp, it absorbs more heat from the surface of the dryer. This increases the flow through the flow tube which is reflected in the mechanism of the control cabinet. The cabinet in turn automatically opens the main steam valve to adjust for the change. A decrease in dampness of the sheet, of course, actuates the control system in reverse.

E. *Air and Moisture Handling*—The dryer system has been partially covered at this point. Air and moisture handling is the next subject to be discussed.

The machine dryers turn the sheet moisture into vapor which is carried away by the air supplied to and exhausted from the hood of the machine. Air is the carrying medium.

In all efficient paper drying systems, it is necessary to use from 60 to 80 tons of air to dry each ton of paper. An examination of a psychrometric chart will show the moisture carrying capacity of air at various temperatures. Air at 70 degrees Fahrenheit, for example, can carry 110 grains per pound, whereas at 90 degrees Fahrenheit it can carry 215 grains per pound. This basic principle explains why it is economical to carry the air supplied to the hood at as high a temperature as practical, for by so doing the volume of air required will be less, with attendant savings in equipment cost.

Obviously all of the air used to carry moisture from the dryer section must be brought in from outdoors and must be heated from outdoor temperature to the temperature required to properly absorb all of the vapor released from the sheet in the dryer section.

In summary, one can readily see that to dry paper uniformly and efficiently, it is necessary to introduce air from outside the paper room, warm it, distribute it where needed in proper quantities throughout the machine room, recover the heat from the exhaust air and vapor, and finally discharge the moisture laden air outside of the mill.

The Bucksport machines are equipped with Ross Engineering airhandling equipment. This includes dryer hoods, air supply fans and ducts, air exhaust fans and ducts, Briner economizers, and Grewin ducts and nozzles.

Each machine is equipped with four 45,000 c.f.m. exhaust fans, four Briner economizers, and four 35,000 c.f.m. supply fans. The exhaust fans have a capacity somewhat in excess of the capacity of the supply fans which means that there is a slight vacuum in the machine room and some leakage from adjacent parts of the mill into the machine room. This leakage must of course be heated to the required temperature of the supply air.

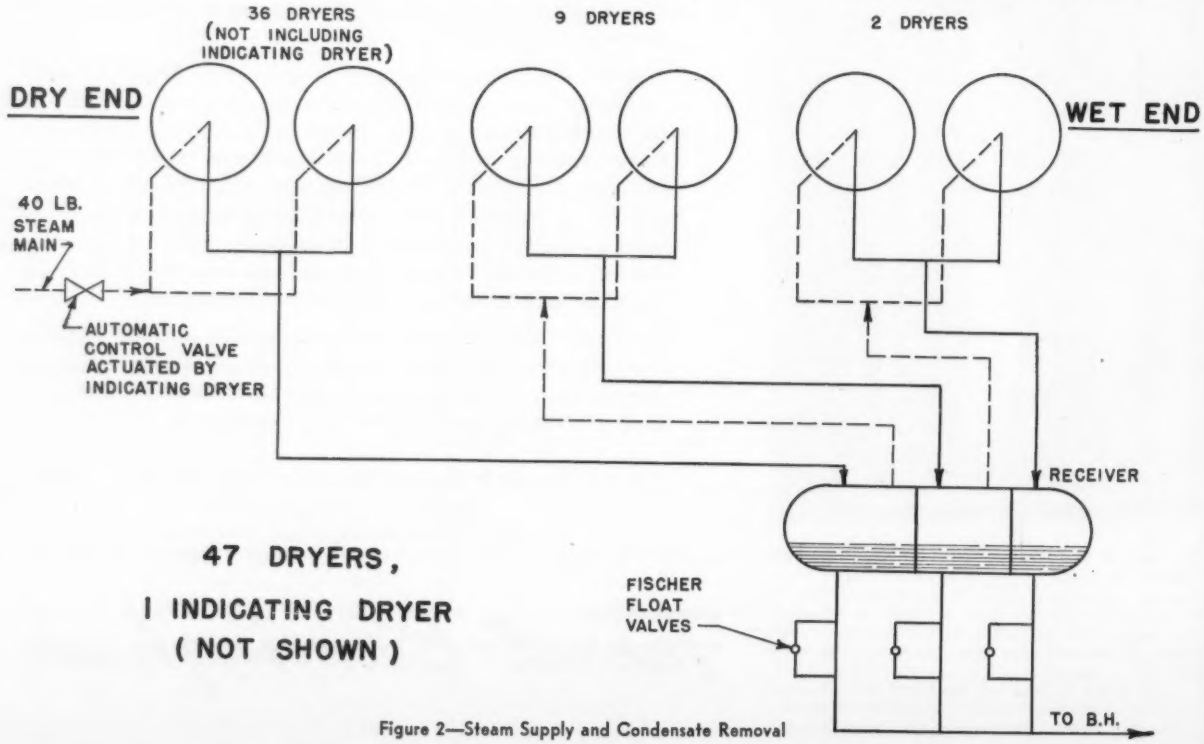


Figure 2—Steam Supply and Condensate Removal

Briner economizers are installed in the exhaust air ducts. The principle of these is illustrated in *Figure 4*. We use two Briners to supply air to dry felts and two to supply warm air to the ceiling to prevent condensation. These economizers consist of narrow cross-sectional passages between thin, corrugated sheets. Heated air is distributed to points of use by ducts. It has been found that vapor laden exhaust air taken from the paper machine at 120 degrees Fahrenheit and cooled in the economizers to 90 degrees Fahrenheit can heat an equal amount of supply air from 30 below zero to 85 degrees Fahrenheit.

To understand the significance of this it should be borne in mind that if the exhaust air was not vapor-laden and was at 120 degrees Fahrenheit, with the incoming air at 30 degrees Fahrenheit below zero, the exhaust air would be cooled down 75 degrees and the supply air would rise 75 degrees, to a temperature of 45 degrees instead of 85 degrees as in the preceeding instance. In other words, the latent heat of the vapor content of the outgoing air in the economizers is such that the supply air can be raised to within 20 degrees to 30 degrees of the exhaust temperature. A further rise can be obtained by use of the steam coil ahead of the supply fan. The lower the outside temperature the more make-up heat required.

The Grewin System previously mentioned is a system for blowing warm air into locations between the dryers where vapor is likely to gather. The system, consists of a blower which draws warm air from the machine room, a heater, and a duct system for distribution. The system serves to eliminate stagnant areas between the dryers and serves to assist the movement of vapor-laden air out of each side of the paper machine. The moist air then rises into the hood.

F. *Dryer Drive*—The next subject to be taken up is the mechanical operation of the dryers. I would like to cover it only briefly, not because it is unimportant but because reference to the proper textbooks will serve to acquaint one with the general arrangement in use in paper mills today.

The 48 dryers of five feet diameter and 228 inch face, interlocked by gear trains, are driven by four sectional drive electric motors of 70 horsepower each. These motors are connected with speed regulators. The dryers are lubricated by oil from a constant head tank above the machines. This tank is supplied from a tank in the basement where returned oil is settled, filtered, and cooled before re-use.

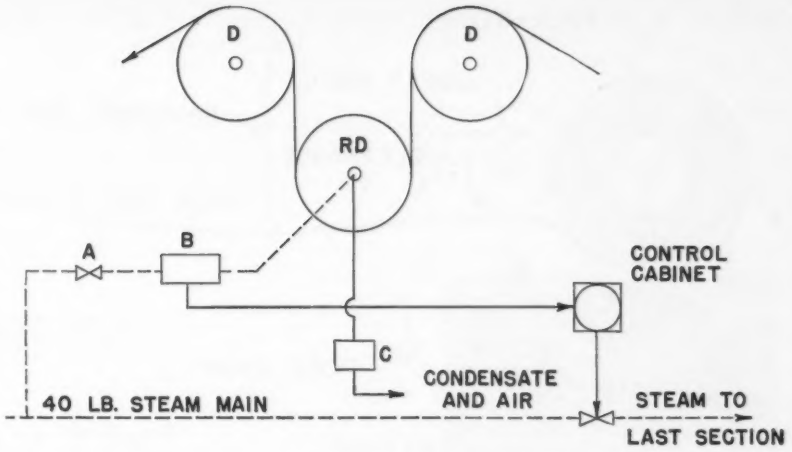


Figure 3—Indicating Dryer

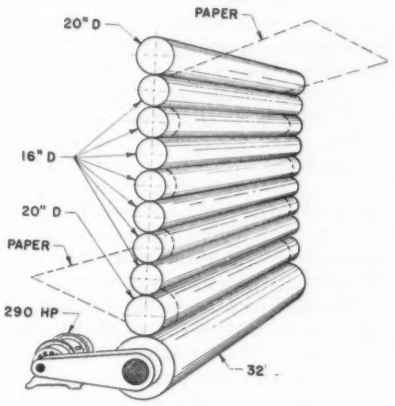


Figure 5—Calender Stack

Spring Roll

As the web of paper leaves the last dryer, it passes under a paper roll supported by spring bearings. This spring roll can rise or fall in its bearings with variations in web tension, thus compensating for variations encountered in drawing the paper from the dryers to the calender stack.

Calender Stack

The calender stacks on both machines are ten roll stacks of conventional design, illustrated in *Figure 5*. The bottom roll is 32 inches in diameter, the next 20 inches, the intermediate 16 inches, and the top roll 20 inches. The stack is driven by the bottom roll with a 290 horsepower motor.

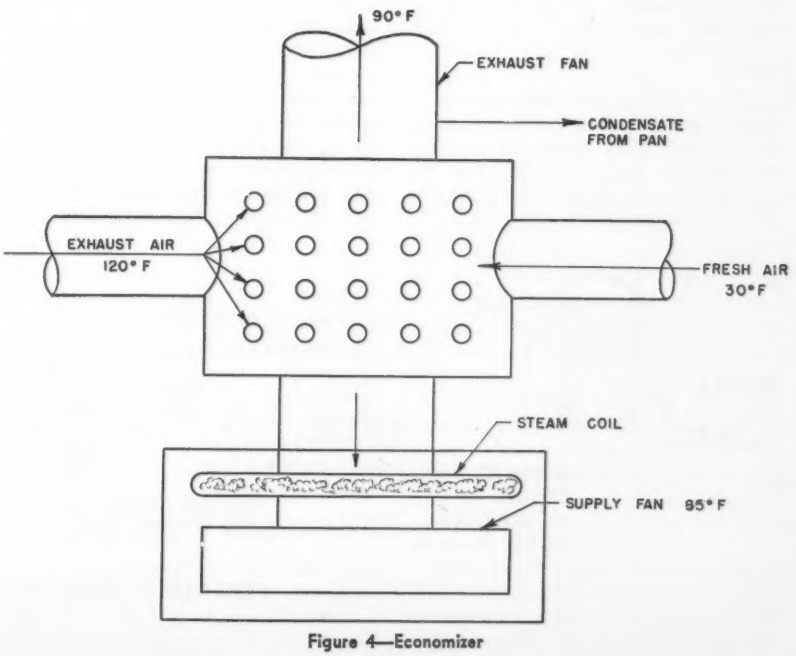


Figure 4—Economizer

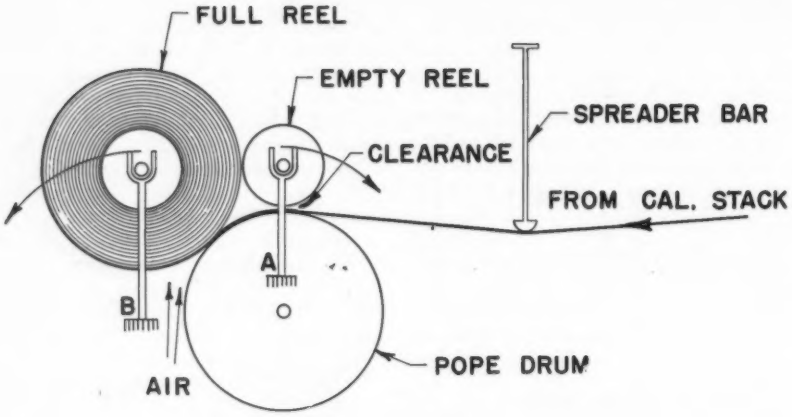


Figure 6—Reel

All rolls are cast iron which has been chilled to give them a fine grain surface and then polished. The first two rolls are crowned to offset the maximum pressure to which the ends of the rolls are subjected in operation. Air is distributed across the incoming face of the stack to keep the rolls cool and also to control uneven expansion of the rolls at localized areas across the width.

Finish is controlled by pressure, and the number of nips through which the paper passes. Nips range from one for a bulky sheet to seven for machine finish printing grades. Five nips are used with supercalendered paper. It is difficult to obtain a good finish at the supercalender if the paper has been overcalendered at the machine. The reason for this is that the supercalenders require relatively high moisture in the sheet to produce a good finish and over calendering at the machine "blackens" such paper.

Reel

The reel shown in *Figure 6* is of the Pope type. The paper is passed from the calender stack under the spreader bar, over the Pope drum, and onto the reel making up. When it is desired to start a new reel, the lever arm (A) is moved forward dropping the empty reel on the paper. The air is turned on and the lever arm and full reel is moved away from the drum. When the full reel slows down, the paper billows up and follows the empty reel until it catches in the nip between the empty reel and Pope drum breaking the paper. The full reel is then lowered to the floor. When the new reel builds up enough, it is shifted from the yoke on lever arm A to the yoke on lever arm B by bringing the two yokes in line and dropping the reel from yoke A into yoke B.

The full reel on the floor is hoisted onto the unwind stand of the winder, see *Figure 7*. The sheet is led under the guide roll, over the slitter roll and board, the carrying roll, spreader bar, and around the back winder roll (B). A shaft with cores on it is placed in the nip between the front and back winder rolls and the winder is started.

Tension is maintained at the unwind stand electrically by a rheostat on the tending side. One end of the guide roll can be moved up or down to adjust the draw of the sheet. The slitter roll and board smooths the paper in preparation for slitting. Slitters are of the shear type. The bottom slitters are driven by individual constant speed motors. The spreader bar enables the operator to spread out his sheet and prevent the edges of adjacent rolls of paper from overlapping at the slit. The latter results in rolls which are difficult if not impossible to break apart at the end of the run. The front and back winder rolls are grooved with a herringbone pattern which gives them a grip on the paper. Both are driven by individual motors, the front roll being run slightly faster than the back to insure a tight wind. Proper control of tension is the most important feature in winding.

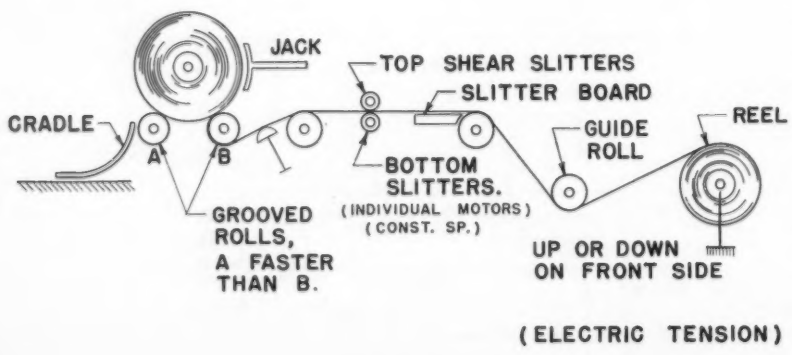


Figure 7—Winder

Paper Machine Drive

Modern paper machines are, as a rule, driven by sectional electric drives. This means that each section such as dryer, calender, press, couch, etc., has its own individual motor.

There being no mechanical connection between the different sections, the speed of these driving motors has to be regulated to an exact degree, otherwise the sheet would pull apart or become slack enough to wrinkle and cause wet cuts.

Not only do these regulators have to function to regulate the speed, but provision is made to adjust the speed regulation of one section to its adjacent sections to take care of draw in the sheet and to maintain this relation.

All speed regulators are referred, or connected, to a master source so that each section regulator has the same basic speed signal to follow.

For close speed regulation, such as this, direct current is generally used. This usually means that large motor-generator sets are employed to change the commercial alternating current to direct current. This requires another set of regulators to insure that the D. C. generator voltage is constant.

Such rapid advances have been made in electronics that it is now common for new machines to have electronic speed and voltage regulators throughout. Economy in production even sometimes justifies the change from older type regulators to modern electronic ones.

For the control of the machine by the operators, push buttons are located on the tending side of the machine so that all individual starting, and stopping, or speed changes, can be made from the tending side by remote control. This means that all of the electrical equipment except the drive motors, and in some instances the section regulators, can be grouped together in a remote location.

Electric drives function very satisfactorily and if given proper care will give reliable service.

Conclusion

An attempt has been made to describe the function of various sections of the dry end of our machines at Bucksport. For further details you are referred to the texts listed below.

1. *Drying of Paper on the Paper Machine,* B. M. Baxter, reprinted from *Paper Industry* and *Paper World,* May 1939, Fritz Publications, 1939.

2. *Stamm Drying Controls,* Installation and Operating Instructions.

3. *Ross Pulp and Paper Mill Machine Room Systems,* J. O. Ross, Engineering Corp., 1938.

4. *The Manufacture of Pulp and Paper,* Vol. V, prepared under the direction of the Joint Textbook Committee of the Paper Industry of the U. S. and Canada, McGraw-Hill Book Co., Inc., 1939.

Fourdrinier Paper Machines—Dry End

C. A. Redden

Graduate, Massachusetts Institute of Technology 1924, B.S. Two years instructor in Mechanical Engineering subjects at M.I.T. Mr. Redden entered the Paper Industry with Hollingsworth & Whitney Co. 1926 and has been with them ever since; twelve years as Chief Engineer.

Introduction

The following discussion is a summary of the principal points discussed in a lecture to the students of a class in Paper Technology at The University of Maine. No attempt will be made to include the detail of that presentation.

The principal purposes of a paper machine are as follows:

(a) To form a uniform, strong sheet, from pulp fibers using water as the vehicle.
(b) To remove the water after the sheet has been formed.
(c) Other functions include:
  1. Surface sizing
  2. Calendering or finishing.

This talk dealt with part (b) namely, water removal or the "dry-end" of a paper machine.

The diagram shows in *Figure 1* a typical Fourdrinier machine, from slice to reel. It also shows progressively the amount of water in the sheet of pulp as it progresses from the wet end to the dry end of the machine.

Fourdrinier. Note that by far the greatest part of the water practically falls out of the sheet through the Fourdrinier wire or is gently sucked out at the flat boxes.

Presses

The presses in their turn remove further water by a pressure between rolls, or forcing action, as in the old time clothes wringer. Under the pressures in the "nip," water is actually forced through and out of the sheet. This water can be seen escaping rapidly down over the surface of the lower roll.

Many lower press rolls are perforated and carry internal suction boxes for increased rate of water removal.

After two or three presses, the sheet passes to the dryers. Let it be emphasized that every effort is made to make the water removal ahead of the dryers as effective and complete as feasible. It costs much more to remove water at the steam heated dryers. Depending on fuel as well as power costs, it will cost 10 to 20 times as much to remove a quantity of water at the dryers as to do the same in the presses.

Dryers

A point is finally reached where the sheet is reluctant to release further water by straight mechanical means, and calls for application of heat.

Notice that the sheet started out at the slice with about 200 parts of water and one part of pulp. Now, entering the dryers, there remain only two parts of water with one of pulp. There were left behind at the Fourdrinier and press sections 198 parts of water.

The last two parts of water hang onto the fibers with increasing determination. To remove this water, it is customary to employ steam dryers. These dryers form the biggest, heaviest, most impressive and costliest part of the entire machine (both first cost, and cost of operation).

The dryers are essentially cast iron drums which carry steam under pressure for the purpose of heating the sheet as it progresses over the dryer surfaces. Dryers are designed for pressures of 30 pounds per square inch up to as high as 150 pounds per square inch in the case of high production machines. All dryers are driven by gearing on the back side.

A diagram, *(Figure 2),* of dryer action as the sheet progresses through the dryers, shows:

(a) Temperature of the sheet.
(b) Rate of evaporation.
(c) Shrinkage of the sheet.

The first few of the dryers serve to bring the sheet, with its moisture, up to the temperature where water vapor escapes rapidly. This will be at a temperature approaching the boiling point of water.

After passing over the first mentioned preheating dryers the sheet releases water vapor in clouds at a fast rate and continues to do so for several dryers. This rapid drying gradually diminishes as the sheet goes along and becomes less wet.

At a point about two-thirds of the way along the dryers most of the easily evaporated, sometimes called "free," water has left the sheet. Possibly one-

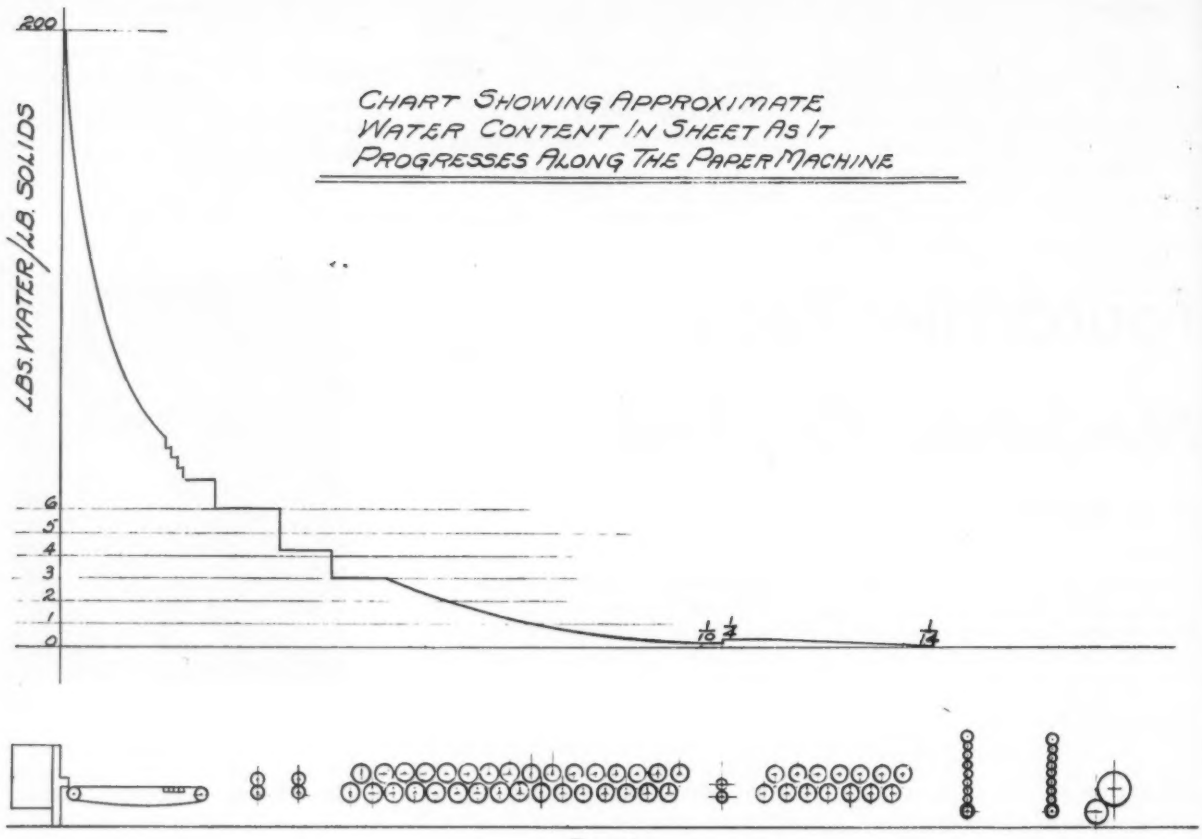


Figure 1

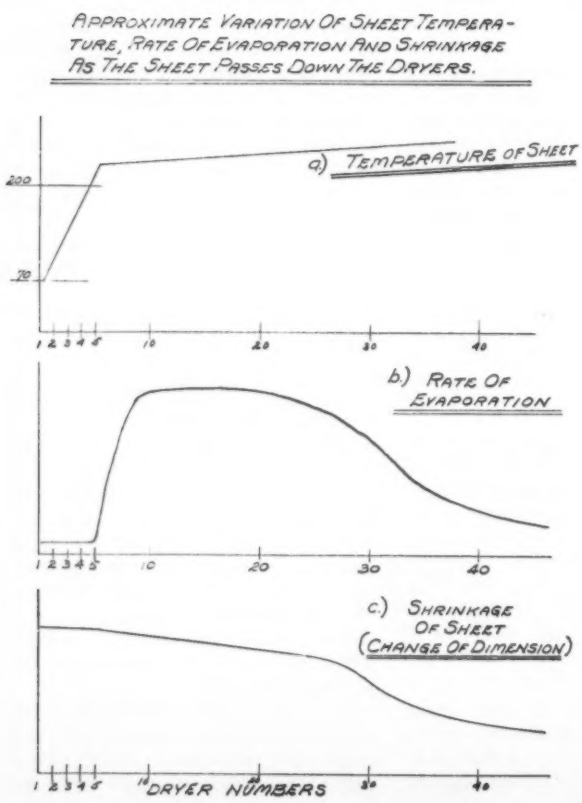


Figure 2

fifth of the water which came to the dryers now remains. This last amount of water is further driven out by the remaining dryers with increasing reluctance until the sheet is delivered from the final dryer with a composition of 93 percent pulp and 7 percent water. Of the original wet-end water 99.965 percent has been removed by the paper machine.

Dryer Steam Control

At the point where the first or easily evaporated water has been removed, there is a more rapid rate of shrinkage of the sheet than takes place either before or after. This effect is made use of in some drying control sensing devices, such as the "tension roll."

The tension roll rides against the drying sheet in such a way as to sense the tension of shrinkage (drying) or reduced tension (less drying), and through a controlling relay system, regulates the admission of steam to the dryers. This is only one of several methods of sensing. Another, increasingly common, method of control uses a selected "sample" dryer and measures the rate of steam flow to it. This rate varies with the sheet dryness. A sensitive air-operated relay instrument effects the necessary steam control.

Dryer Felts

Dryer felts, generally of heavy cotton canvas, are so held against the dryers as to hold the sheet of paper in close contact with the dryers. The purpose of dryer felts are as follows:

1. More rapid heat transfer to the sheet.
2. Felt absorbs some moisture, like a blotter, to be released later in the felt travel.
3. Helps carry and hold the sheet.

Air Circulation

Air circulation is provided to remove the vapors quickly and is accomplished by the following:

(a) A hood with exhausters.
(b) Hot air blowing into the spaces between dryers, typical of which is the Grewin system. This can increase drying capacity as much as 8 percent.
(c) Other hot air duct systems are used which contribute a helpful gain in rate of drying of the dryer section.

Some idea of the vast amount of air circulation required to carry the moisture away from the dryer section can be gained from the following typical case.

A 100 ton/day paper machine requires: Approximately 40,000 to 50,000 cubic feet of air per minute or approximately 2,000 to 2,500 tons/day of air to carry away the moisture without drip, or rain, from the hoods or the exhaust.

The object of air circulation is to keep the evaporated moisture and air mixture above the dew-point until it is safely out of the machine room.

SECTION OF DRYER AND STEAM JOINT

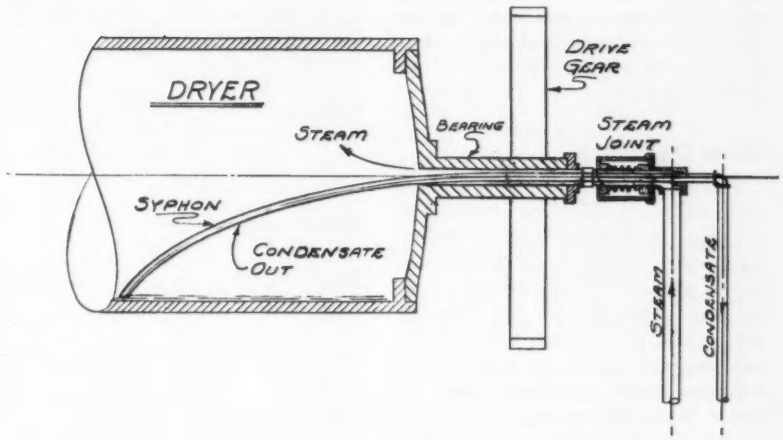


Figure 3

Economizers

A very substantial amount of heat escapes with the vapor laden air from the machine room. This may represent an amount of fuel worth $3.00 per ton of paper. Efforts to reduce this loss generally result in keeping the air flow as close to the dew point as is safe, i. e. no excess air.

A SIMPLE DRYER CONDENSATE SYSTEM

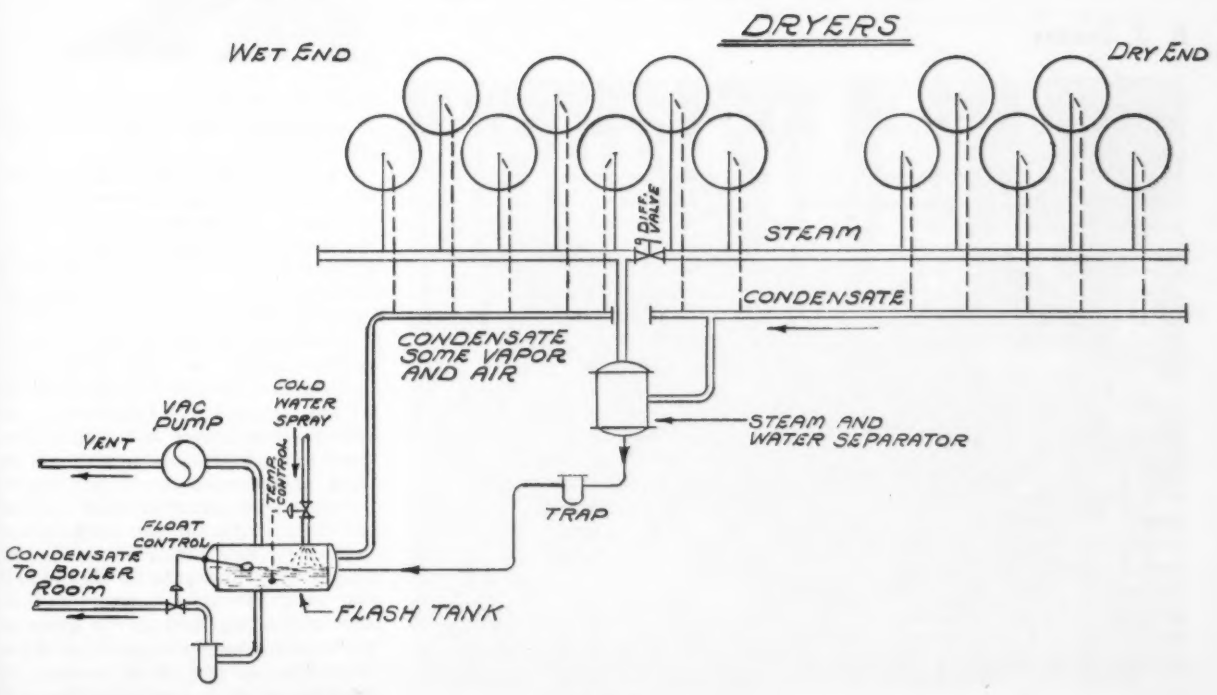


Figure 4

A heat exchanger, called an "economizer" has been used for several years in northern mills. They employ the exhaust vapors and air to heat up new air on its entry to the machine room. A very considerable amount of heat can be returned thereby to the machine room.

Minton Dryer

This drying section employs a totally enclosed, heavy, cast iron chamber entirely surrounding the usual steam drying drums. A comparatively high vacuum is applied which eliminates the air for the most part in the chamber. Thus, air which was essential for sweeping the vapors out of previously described dryers, is almost completely absent in the Minton dryer. The result of the vacuum is that drying can proceed at much lower temperature than on the usual steam dryers. Vapors as discharged pass over to a condenser for removal as condensate. A few of these Minton dryers are in use, mostly as pulp dryers. The construction is costly and operation somewhat more complex than for ordinary dryers. On the other hand, these are compensating advantages:

(a) Steam costs are considerably lower.
(b) The sheet is subjected to lower temperatures, retaining more of its strength and with less loss in "color" or brightness.

Condensate Removal

All steam dryers are in effect "condensers" and in collecting condensate must be continuously emptied of this hot water to permit further steam to go to work in the dryer. This is accomplished effectively with "syphons" extending through the dryer journal and reaching into the collecting condensate on the shell, *(Figure 3)*. After removal of condensate from the several dryers it is conducted by way of a manifold pipe to a "flash" tank where a separation takes place. Condensate is delivered to a return pump, while vapor and non-condensable gases, if present, are piped to a few dryers at the wet-end which are operated at reduced pressure and temperature. Thence the condensate removal is similarly carried out. Non-condensable gases must be vented and usually require vacuum pumping to insure adequate removal. A diagram of a typical simple condensate system is presented in *Figure 4*.

Conclusion

It is to be emphasized that as much water must be removed from the sheet as is economically feasible before it reaches the dryer section.

Within the dryer section the rate of supply of steam to the drying cylinders must be commensurate with the ability of the sheet to give up its water content. Advantage must also be taken of dryer felts to increase the rate of heat transfer and circulation of air to facilitate the removal of water vapor.

Paper Machine Drive Fundamentals

E. J. Justus[1]

Graduate of Georgia Tech. Under the "Cooperative Plan" of studying engineering, he obtained practical experience in a foundry and in a machine shop.
During World War II, he served in the air force as an aircraft maintenance officer. His overseas experience included service in the Phillipines, Okinawa and Japan.
After working as an experimental engineer and electrical control engineer at Fairbanks-Morse & Co., Mr. Justus came to Beloit Iron Works as electrical engineer and deveolpment engineer. During the course of his service with Beloit Iron Works, Mr. Justus has visited mills in Canada as well as in all sections of the United States.

Introduction

No paper machine is better than its drive. This axiom is heard wherever paper machines are discussed. A paper machine is judged according to its quantity, quality and economy of production of paper. The same criteria should be used in judging the drive for the machine. A drive is good or bad because of its effects in the over-all operating efficiency and economy of the paper machine.

Perhaps the best approach to describing the fundamentals of a paper machine drive would be to establish what is required of the drive, what its functions are and what it must do. The very nature and make-up of the paper making process depends on the successive performance of several separate and distinctive operations on a tender web of separate fibres as it is passed from the forming section to presses, to the dryers, to the size press, to the calenders and to the reel or cutter, etc.

The first section must actually form the web from a suspension of fibres and water. To assure uniform caliper and uniform formation of the sheet, it is essential that the rate of removal of fibres be matched to the rate of supply of fibres to the forming section. Since it is more practical to deliver the stock to the machine at a fixed rate, it is essential that the speed of the forming section be accurately held also to assure uniform caliper and weight. Because the web as initially formed is so weak as compared to the powers required to perform the pressing and run the other sections of the machine, the drive must supply the power. It is also evident that the speed of the presses and each successive section must be very closely matched to the speed of the forming section to prevent either the pulling in two of the web or the development of an ever increasing loop of material between any two sections.

[1] Engineer, Beloit Iron Works, Beloit, Wis.

1671—BASEMENT LINESHAFT FOR 192" FOURDRINIER MACHINE

Figure 1

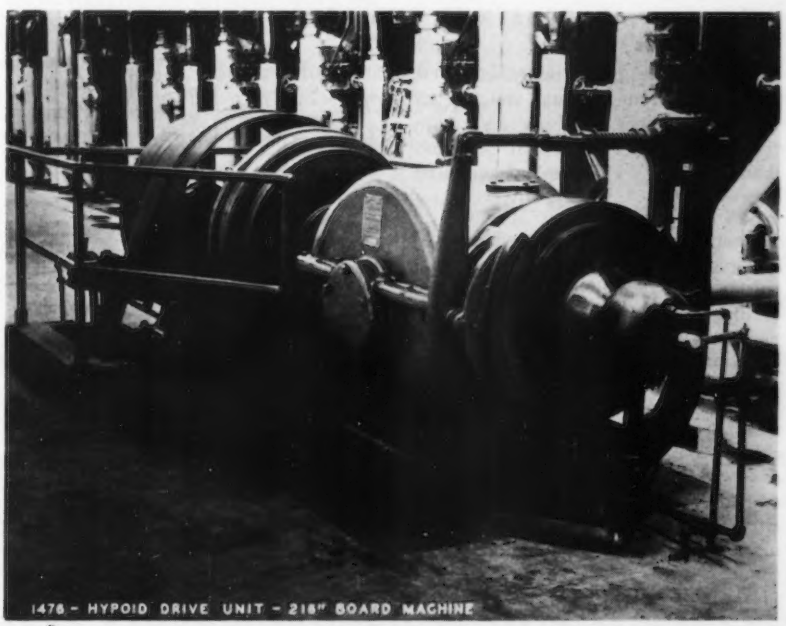
From the above, we have the first requirement of a paper machine drive. *A paper machine drive must supply the power required and accurately hold the speed of each section.* A corollary to this is that the speed relationship of each section to each other section must be held constant.

The simple and obvious solution to these requirements would be to accurately regulate the speed of a single shaft and to gear directly from this shaft to each separate section. An electrical solution would be to drive each section with a synchronous motor geared directly into each section and to supply the synchronous section motors with a frequency proportional to the desired speed of the machine.

However, there is a second requirement of a paper machine drive dictated by economics, paper making requirements, and the nature of the paper machine. *Within a range of approximately 2 per cent to 10 per cent, each section must be infinitely variable in speed with respect to adjacent sections.*

Although the range of adjustment needed is small, a greater part of the complexity and operating difficulties of paper machine drives are encountered in satisfying this second requirement. Most of the means employed to satisfy the need for infinite variation between the sections results in a compromise in the accuracy of holding the accurate speed relationship between sections or "draw" (as it is commonly called). Draw or difference in speed between sections is necessary to insure that the sheet stays taut through the separate sections of the machine. It is necessary to "draw" the sheet out a little from couch to press, from press to press, from dryer to calender, etc. In passing through a press, a sheet tends to gain a little in length. Different sheets of different furnish and weight require varying draws because they change in length differently in the presses. Draw is also effected in that even on a given press different nip pressures may mean slightly different peripheral speed through the nip, even with the same revolutions per minute of the roll, because of the compressibility of the felt and the roll covering. Even as the felts wear, surface speeds can change slightly for a given revolution per minute of the roll. The paper maker also uses the adjustment of draw between sections to correct sheet release problems. By pulling a little faster from the 2nd press, the sheet can be made to release from a 1st press top roll at a lower point and provide safer running, prevent blowing, prevent wrinkling, etc. In the critical draw between the couch and the first press, the first press must be run just enough faster than the couch to insure that the sheet is pulled from the wire at the right point to run safely onto the first press felt. Just how much faster the first press must run than the couch is not a definite figure, but is determined solely by paper making considerations such as how the sheet releases and other variables. Like so many things in paper making, the couch draw and other draws are empirical values and not subject to an exact theoretical determination. As a rule, it is usually best to run with as low a draw between sections as conditions permit because the sheet formation will be less disturbed and a better testing sheet will result. On the dry end of the machine, percentage of moisture will effect the shrinkage of the sheet and thus the draws required.

Still another important reason for the need of the infinite variation between sections lies in the economic ad-



1478 - HYPOID DRIVE UNIT - 218" BOARD MACHINE

Figure 2

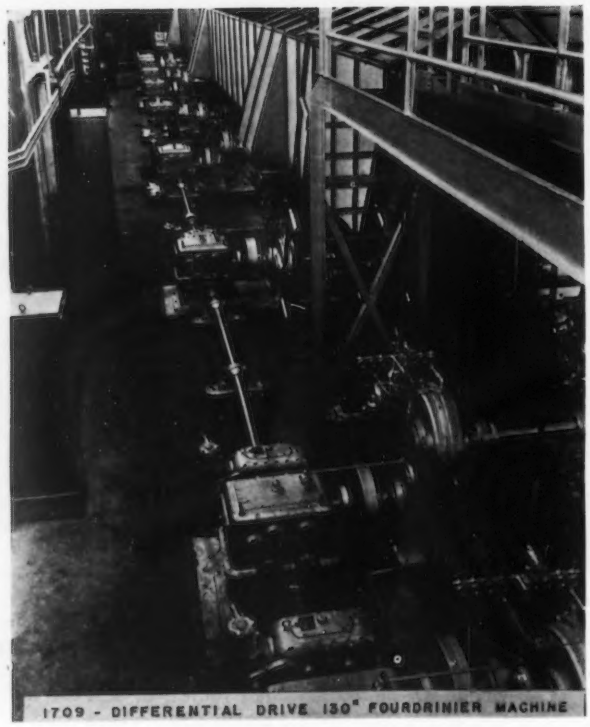


Figure 3

vantages of being able to resurface driving rolls by grinding off the diameter. The change in relative surface speed that would result with respect to adjacent sections if solid gearing were used can be corrected by an adjustment in the drive. Thus, it is evident that infinite adjustment in speed of adjacent sections is a practical requirement of a paper machine drive.

Types of Drives

There have been many different types of both mechanical and electric drives for paper machine and many drives are a combination of both mechanical and electrical equipment. However, one basic difference in drives lies in the manner in which the different sections of the machine are tied together to run at the same speed level, and a second lies in the method of draw adjustment between the sections of the machine. Another way of breaking down the classification of drives is to single power input or multiple power input machines, the multiple source of power input machines being mostly electrical section drives, and the single power input machines being mostly lineshaft machines. Of course, again there are machines that actually are a mixture of the two wherein most all of the power is supplied from a single prime mover and then auxiliary helper drives are supplied for certain rolls.

Mechanical Drives

In general, drives are referred to as either mechanical or electrical. A mechanical drive is any drive that ties the separate sections of the machine together by mechanical means, such as the old fashioned rope drive or a modern lineshaft drive. In either case, the almost universal means of adjusting the draw between the sections is by means of a cone pulley arrangement in the power train to each section. Cone pulleys with leather belts have proved over the years to be a very reliable and satisfactory means of supplying power and of providing the necessary draw adjustment on paper machines while tieing the speed of each section back in a fixed relationship to the lineshaft speed. On such drives, the speed of the machine as a whole is controlled by the speed of the prime mover. Water wheels, steam engines, steam turbines, and electric motors are all used to power the lineshaft drives. *Figure 1* shows a basement lineshaft with the cone pulleys and belts going up to the machine to the various sections. For paper making requirements it is necessary only that the prime mover governor provide accuracy of speed regulation throughout the speed range of a paper machine in the order of ½ to 1 per cent.

The advantages of belts lie in minimum of maintenance, in ease of training personnel to maintain them, and in their fundamental simplicity. The main limitations on pulley and belt arrangements lie in the limited power ability of the belts in that the width of belts operating over the unequal radii of cone pulleys is limited. In general, pulleys are tapered from ⅜ to ¾ inch per foot of length on the diameter. Tapers in excess of ¾ inch per foot are considered excessive. Belt speeds are usually limited to approximately 5000 feet per minute with some speeded up machines and rebuilt machines going up to 6000 feet per minute. With standard pulley diameters, this means that most lineshafts

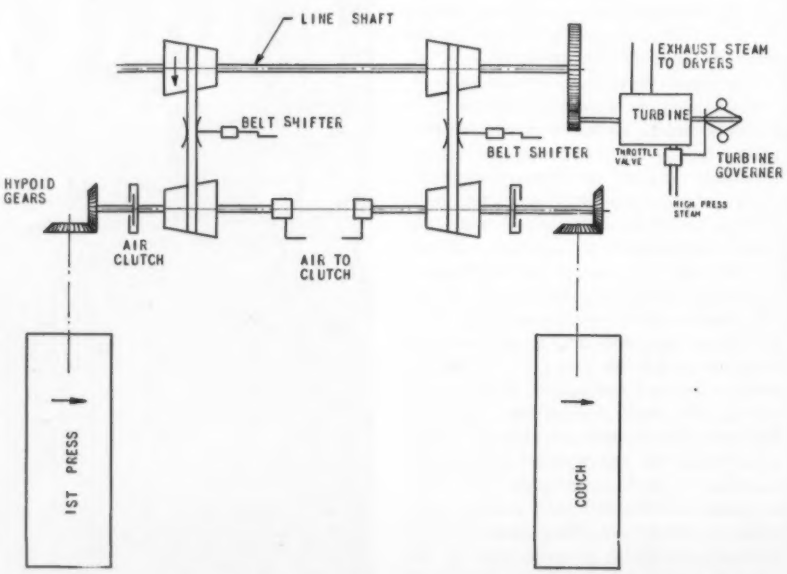
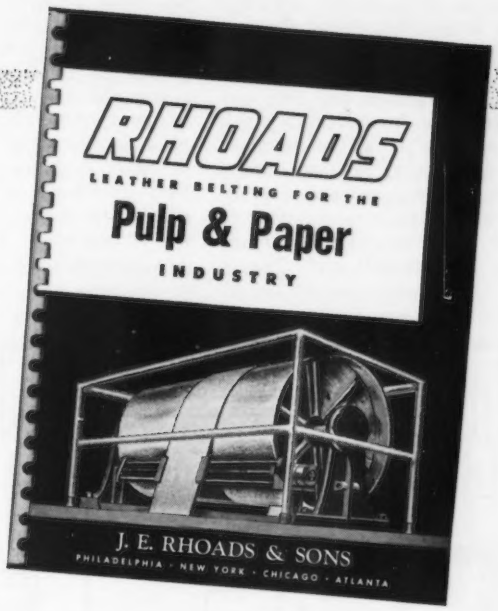


Figure 4—Schematic Representation of Line Shaft Drive with Cone Pulley Draw Adjustment

"If the Paper Machine in Your Mill is Belt Driven... You Need This Handbook"



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are limited to approximately 600 revolutions per minute. Belt drives of 200 horsepower per section at paper speeds in excess of 1500 feet per minute have proven very satisfactory.

To operate satisfactorily, belts must have sufficient tension to prevent slipping. Since most paper machine drives have fixed center distances between the basement or overhead lineshaft and the pulley on the right angle drive on the machine floor with the two shafts vertically spaced and without auxiliary belt tightener arrangements, some care must be exercised in maintaining the belts to the proper tension or length. A belt will normally require shortening two to three times during the first year and not more than once a year after that. If loads are kept within normal design factors, belt life may be expected to be from 5 to 15 years.

In conjunction with the standard lineshaft drive, a right angle spiral bevel or hypoid gear reducer is usually employed on the machine floor to accomplish the necessary 90 degree turn from the lineshaft centerline to the indrive centerline and to accomplish the necessary speed reduction. Hypoid gear units have come into general favor for lineshaft drives because the construction of the hypoid gear permits both the pinion shaft and the ring gear shaft to extend clear through the case thus eliminating the necessity for an overhung pinion or a ring gear. Also, some form of air clutch (because of its ease of control and smoothness of operation) has become rather standard with the paper machine manufacturers. The extension of the shafts in hypoid units permits drilling an air passage through one shaft to supply the clutch. The single lineshaft for an entire machine from which each section is driven has proved to be an excellent means of tieing the separate sections together in speed because it is basically so simple and yet positive.

Figure 2 shows a dryer section hypoid drive for a large kraft board machine. The motor operated belt shifter can be seen at the left along the pulley. The air clutch will be noted in between the pulley and the gear box. Attached to the extended pinion shaft on the right hand side can be seen the water cooled brake for stopping the dryers along with the rotary seal for supplying air to the clutch thru the center of the pinion shaft. A cooling water pipe for the brake is also evident. Since these drive units are on the backside of the machine, pushbutton controls for the belt shifter motors are usually provided on the front side of the machine. The hypoid drive unit shown is rated approximately 250 horsepower.

Recently, another means of attaining the infinite draw adjustment between sections of a machine driven from a single lineshaft has been developed. This drive uses a mechanical gear type differential to add to the major portion of the power transmitted a small variable increment of power or speed. This in turn causes the total output speed to be infinitely variable over a small range. Since this drive utilizes the fact that it is necessary to vary only a small portion of the total power input, it achieves the desirable result

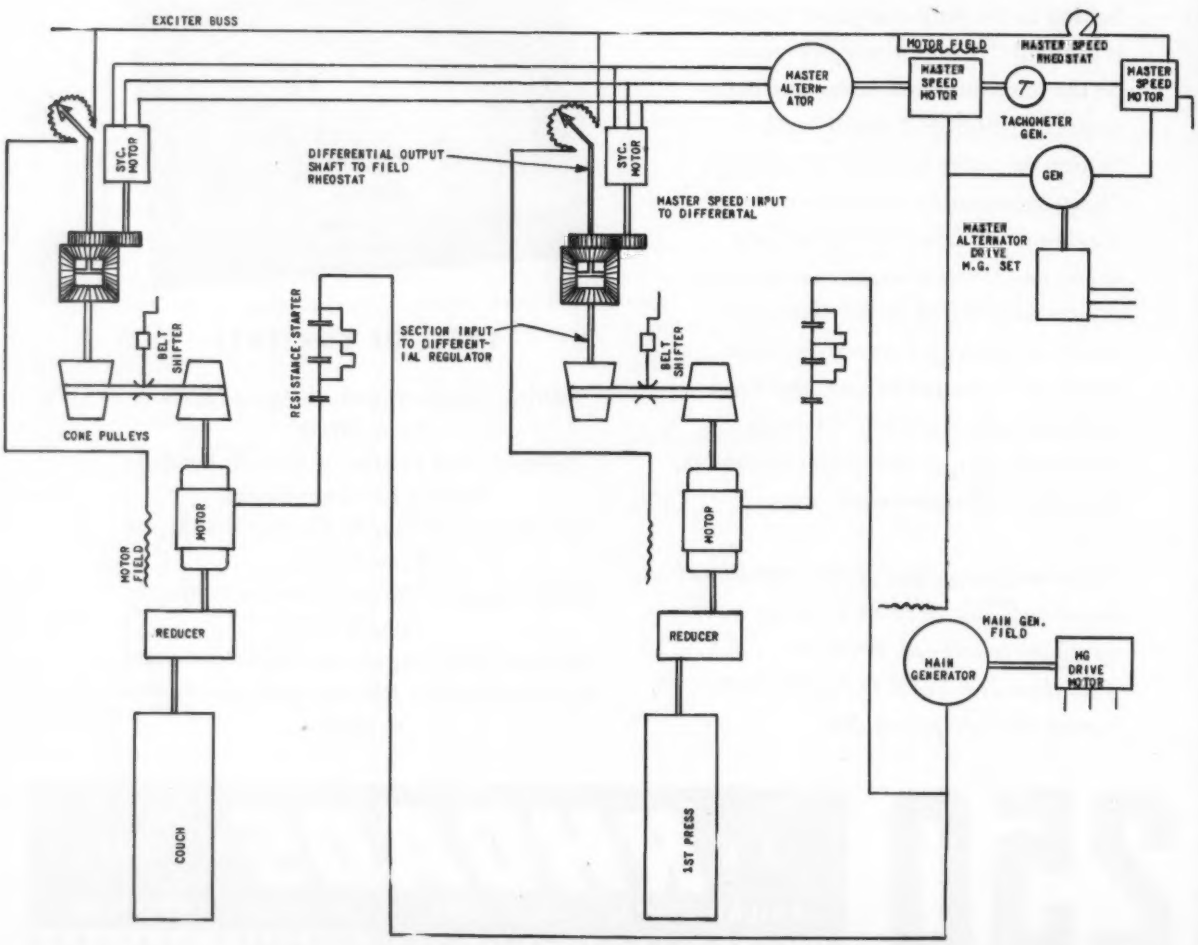

Figure 5—Differential Regulator-Harland Type Drive

of providing an infinite speed adjustment over a small range and yet maintaining a positive ratio at any given setting.

Figure 3 illustrates an installation of the latest type mechanical differential drive as installed on a new paper machine. In the foreground can be seen the transfer reduction gear case and the indrive to a press. Between the transfer case and the differential gear unit thru which passes the lineshaft, is the air actuated clutch. The differential gear box is entirely enclosed and forced feed lubrication is provided for all gears. Approximately midway in the high speed lineshaft can be seen the single electric motor which supplies power to the entire machine thru the lineshaft. Draw adjustment is accomplished by the small electric motor evident at the upper left hand corner of each differential gear unit which acts to change the effective ratio thru differential unit to the clutch shaft.

One of the outstanding operating characteristics of this new drive with its positive yet infinitely variable ratio between sections is that running draw variation between sections from a given setting has been eliminated. This means that total draws from couch to reel can be greatly reduced, in some cases to as low as 2 per cent.

To give some idea of actual paper machine draws as they exist, consider an actual newsprint machine running at 1500 feet per minute on the dryers. The fourdrinier ran only 1420 feet per minute, the first press 1475 feet per minute, and the second press 1490 feet per minute. On a machine making kraft board, the couch speed was 1250 feet per minute, the first press 1275 feet per minute, the second press 1290 and the dryers 1300 feet per minute.

On the dry end of the machine, draws in the order of ½ per cent are common between dryer and calender and between calender and reel. Draws, of course, vary with grades of paper but in general the lighter grades of paper require more draw. On newsprint machines, the large draw between the couch and first press is required to get the sheet off the wire after passing over the suction area of the couch.

Figure 4 is a schematic representation in a lineshaft drive with cone pulley draw adjustment. The over-all speed of the machine is adjusted by compressing a spring on the fly ball governor which in turn sets the speed of the turbine driving the lineshaft through a reduction gear. On modern machine installations, the machine tender can usually adjust the speed of the governor of the turbine by means of pushbuttons on the machine floor. The governor and the turbine itself are usually installed in the basement. On such a drive, an important advantage in fuel savings can be attained in that the turbine can be used as a reduction valve to reduce boiler pressure to that desired for the machine for drying paper. A back pressure regulator can be used to maintain a given back pressure on the turbine for drying purposes. The drop in steam pressure across the turbine will supply a low cost source of power to drive the machine. Draw adjustment for each individual section is obtained by shifting the belts along the cone pulleys. Each section is individually stopped and started by means of a clutch between the cone pulley and the pinion shaft. In designing clutches for dryer sections and other high enertia sections, it is essential that the clutches have sufficient thermal capacity to accelerate the dryer section without undue heating of the clutch. As can be seen from the diagram, this is essentially a very simple and direct approach to the paper machine drive problem and represents the greater number of installed paper machine drives.

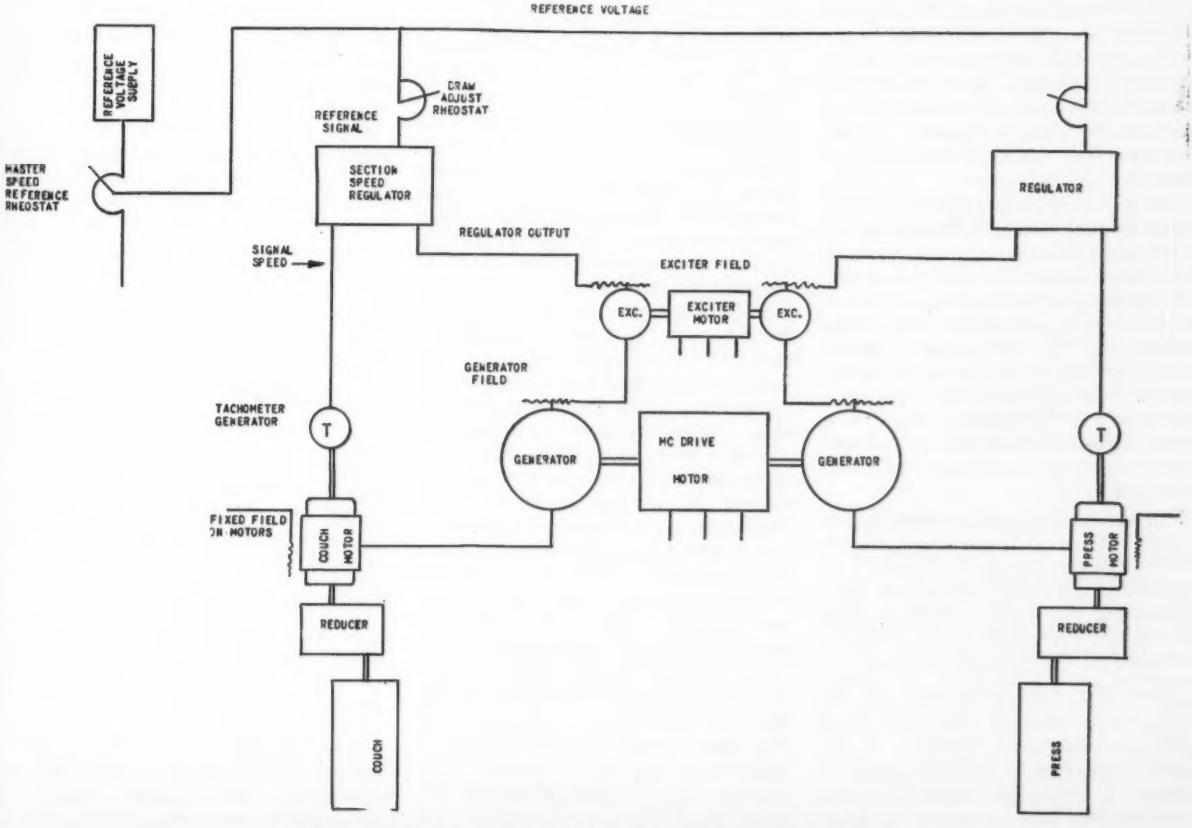

Figure 6—Multiple Generator, Individual Speed Regulated Sectional Drive

Electric Drives

There are many types of electric drives and they can be classified in one of several different ways. Perhaps the first classification would be single generator drives or multiple generator drives.

In the single generator drive, all of the section motors are driven from a single power source, the voltage of this power source being varied directly with the speed desired on a paper machine. The regulating means for adjusting the relative speed or draw of each individual section operates on the field of each section motor. Sections are stopped and started by resistance starters off of the main generator, or in some cases accelerating generators and crawling generators are used and then when the section is up to speed, it is transferred to the large single generator.

In multiple generator drives, each speed regulated section has its own generator. In this type of drive, each section motor has a constant field and the regulating device for adjusting the speed of the section operates on the field of the section generator. In general, on electric drives required to operate over a wide speed range, the multiple generator drive offers advantages in regulation because of the relatively constant speed of the machine on which the regulation is applied.

Drives which have one large motor driving a lineshaft from which each separate section is driven by mechanical means can be classified as mechanical drives with electrical prime movers.

Another fundamental means of classifying electric drives would be according to the type of regulator used. For many years, the differential type of regulator, which was made in several different styles, was used almost exclusively. The differential regulator is in actuality a revolution matching device. Since World War II, many electronic speed regulated drives have been installed wherein an electric speed regulator is applied to each section motor.

To these classifications must be added the electrical helper drive. Helper drives provide torque assistance to a particular section or roll without speed regulating the section. Helper drives are almost universally current regulated variable voltage DC motors.

Following are descriptions of several basic types of electrical drives with accompanying sketches of the basic regulating schemes. It should be borne in mind that there are many combinations and variations in which the various parts may be applied although the fundamentals of the drives are not changed.

Please refer to *Figure 5.* This electrical drive is commonly called a differential regulator or Harland type drive. The speed of the machine as a whole is determined by the setting of the speed of the master alternator which is driven by a speed regulated variable voltage DC motor. The speed regulation system of the master alternator and thus of the paper machine is depicted in the upper right hand corner. The main generator is regulated to supply a voltage proportional to the speed setting of the paper machine. The master alternator in turn drives synchronous motors on each of the differential type regulators on each section of the machine. It can be seen that the other input shaft of the differential type regulator is driven by cone pulleys from the section motor.

Draw adjustment is obtained by shifting the belts one way or the other on the cone pulleys. If the input bevel gear to the differential regulator from the cone pulleys and the input from the synchronous motor for that particular section are not running exactly the same speed, the other two bevel gears will cause the center shaft (on which they are mounted and which extends through the synchronous motor bevel gear) to rotate. The rotation of this shaft acts to operate a rheostat which in turn varies the field of the motor of the section so as to correct the speed of the section motor and cause the shaft on which the bevel gears are mounted to seek a position corresponding to the load demand. When in operation, the center shaft on which the bevel gears and the rheostat are mounted is relatively stationary, moving only enough to cause the rheostat to correct for load changes. This type of drive can be modified to have a single generator for each section with the differential regulator rheostat operating in the field of the particular section generator. On the drive shown in *Figure 5,* a single generator is used, the voltage of which is made proportional to paper machine speed. The sections are started from the single large generator by means of the resistance starters shown.

The essence of the type of drive in *Figure 5* is it uses a revolution matching regulator. That is, the differential regulator actually makes each section make a definite number of revolutions compared to each other section. The ratio of revolutions is determined by the gearing and is variable over a small range by the cone pulleys driving one side of the differential regulator from the section motor. The only true speed regulator as such is that driving the master alternator and the revolutions of the sections are matched to its revolutions. Modern versions of differential regulators provide for forcing action, and anti-hunt features which have been added provide quicker response to errors and to reduce cyclic draw variations.

Figure 6 is a schematic representation of a multiple generator, tachometer generator individually speed regulated sectional drive. Into each speed regulator is fed a reference voltage from some accurate source. Also into each speed regulator is fed a voltage which comes from the tachometer generator on each section which is proportional to the speed of the section. The speed regulator compares the reference voltage and the section speed voltage and if a difference exists an output is supplied to the exciter which in turn corrects the main generator field voltage. The correction is in such a direction as to change the speed of the section to make the output of the tachometer generator match that of the reference voltage.

Draw adjustment on this type of drive is provided by means of a rheostat in the tachometer generator output, or can be provided by means of a potentiometer or rheostat in the reference voltage input to the section regulator. Speed change on the machine as a whole is provided by adjusting the level of the reference voltage fed to each section speed regulator by means of the master speed rheostat.

The multiple generator drive provides some advantages, particularly with respect to maneuvering. That is, such features as crawl, jog, wash-up speeds, and reversing are easily incorporated. Also on dryers and other high inertia sections, current limit acceleration and deceleration are provided.

When separate speed regulation of sections is used, one design and maintenance difficulty is the extreme accuracy and stability of regulation needed to insure that the difference in speed between sections or draws does not exceed acceptable values. This is true because the sections are not "locked" or regulated together but each one is separate. Most of the electronic drives installed in the United States since 1946 have been of this type.

Another way of classifying electric drives is to divide them into speed regulated drives (which are sectional drives) and helper drives (which are actually current regulated or torque regulated drives). On cylinder board machines and some of the later design fourdrinier and Yankee machines where more than one electric motor may be used driving onto a given felt,

or where sections of the machine are run closed (with positive contact in the press nips), helper drives are used.

It is fundamental that two speed regulated devices cannot be used on the same unit or section without imposing a drooping speed characteristic on one or both, or in having the speed regulators fight each other. For instance, on a cylinder board machine, *Figure 7,* where the felt will pass over as many as seven cylinder moulds in succession, then to a suction drum roll and several baby presses and onto a first main press, only one of these sections should be speed regulated or driven from a lineshaft.

The power demanded by all of these successive sections is too great to be transmitted through the felt. On most cylinder machines, it is advantageous from a felt life standpoint to supply the power to the successive cylinder molds and presses. When such helper drives are applied, they are normally driven from a generator which is regulated automatically to pull a certain amount of current. Since the motor fields are kept constant, the constant current in the motors results in a constant torque. As the section is speeded up or slowed down by the speed setting drive, which would be on a first main press, the current regulator automatically weakens or strengthens the field of the helper generator to produce a constant load current. Load distribution between the group of motors driven from the one current regulated generator is accomplished normally by field rheostats in the individual motor fields. A standard sequence for interlocking one of these drives having a separate motor-generator set with a current regulated DC generator is as follows:

The drive for the main press is from a lineshaft through an air clutch and bevel gear drive unit and cone pulleys. When the machine tender operates the air valve to start the section, the air in the clutch line picks up a pressure switch which energizes the helper motors. However, air is prevented from going over to the clutch by a solenoid valve. In turn, a current relay in the helper motor circuit picks up when the helper motor current builds up, energizing the solenoid valve and allowing air to go over to the clutch, thus applying torque to the main press from the lineshaft. The clutch will accelerate the main press up to speed bringing the other presses and molds along until the felt is up to speed and the clutch "seals in." The helper motors will continue to supply their helping torque during acceleration and after the section is up to speed. This sequence assures that helper current and torque is applied by helper motors before the clutch is allowed to engage. Therefore, all the torque for accelerating and driving the sections need not be supplied from the lineshaft through the clutch and through the felt from this main press.

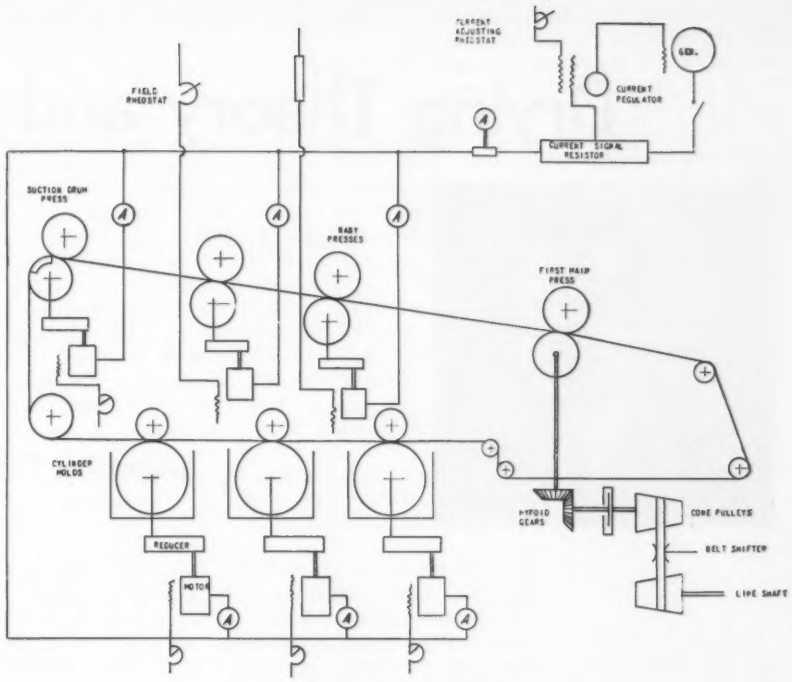

Figure 7—Cylinder Board Machine

General

Paper machines are normally required to operate on a continuous basis of 24 hours a day and sometimes 7 days a week. The factors used in selecting bearings, gears, electric motors, generators, and all components should be very liberal. Wherever possible, components should be kept relatively cool, dry and clean. With respect to electric motors, it is standard to supply totally enclosed forced ventilated motors. The air supply to the forced ventilating system should be located so as to insure a supply of cool, clean air to all rotating machines. In general, for section drives it is considered advisable to use motors and separate reducers instead of gear motors. Standard procedure for some years has been to specify 1150 revolutions per minute base speed electric drive motors instead of higher speed motors.

On mechanical parts, particular attention must be paid to gear tooth loads, bearing loads, lubrication, etc. The keynote of successful drive performance is conservative design.

Power Requirements

The power constants developed by the Technical Assn. of the Pulp and Paper Industry are used almost universally in determining the proper horsepower for paper machines. These constants, of course, can always be tempered by power readings from machines representative of a particular application. The power constants for couches to make kraft or news at speeds above 1000 feet per minute is 0.1 horsepower per inch of width per 100 feet per minute. Thus, the recommended drive power for a couch to run 2000 feet per minute and 200 inch wire width would be 400 horsepower. For a press on the same machine, the drive constant is .03 horsepower per inch of width per 100 feet per minute. This would call for 120 installed horsepower for each press. The paper machine drive manufacturers are available to recommend proper drives for new machines or for old machines that must be speeded up.

Conclusion

From the foregoing, it is apparent that there may be several solutions to any particular paper machine drive problem. It is also apparent that the final answer must provide for accurate speed regulation of the machine as a whole, absence from excessive draw variations and suitable draw adjustment. The features must be had along with good operating efficiency, extreme reliability, and minimum of maintenance.

Drying Theory and Practice

Charles E. Hill

and

Clarence J. Pyle

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Mr. Pyle is a graduate of the University of Delaware and holds a degree in Mechanical Engineering. He worked with the d Pont Co. for three and one-half years, the Scott Paper Co., three years, Doeskin Products, Inc., one year and is presently a Project Engineer with The Puesy and Jones Corp., with whom he has bee associated since 1951.

PART I

Drying Theory

Introduction

To fully appreciate the function of a dryer and to properly view any system design to bring heat to the dryer, it is necessary to recall certain basic principles of heat transmission.

Basically, heat is a form of energy developed as the relative motion among the molecules of the heated body.

The three methods by which heat may be transferred are (1) conduction, (2) convection, and (3) radiation. In conduction the vibratory motion is transmitted progressively from molecule to molecule by impact. In convection the vibrating mass is conveyed bodily from one place to another by circulation or by mixing within a fluid. In radiation the vibrating molecules set up waves in the ether which travel through space just as light or radio waves do. These transmitted waves when re-absorbed manifest themselves as sensible heat.

In actual drying on the paper machine all three methods of heat transfer occur simultaneously. In studying them, however, their effect is combined and considered as conduction.

Certain commonly used symbols are employed when dealing with heat transfer problems. The following nomenclature, abstracted from an article in Mechanical Engineering *(1)*, has been approved by the American Standards Association. Any consistent set of units may be used; those shown in parentheses are the units commonly employed by engineers.

A . . . Area (sq. ft.)
t . . . Temperature (degree of Fahrenheit, °F)
L . . . Length of path of heat flow, thickness (inches)
Q . . . Total quantity of heat transferred (British Thermal Units, BTU's)
k . . . Thermal conductivity (BTU/hr/sq.ft./°F/in)
h . . . Coefficient of heat transfer (BTU/hr/sq.ft./°F)
C . . . Thermal conductance (BTU/hr/°F)
U . . . Overall coefficient of heat transfer (BTU/hr/sq.ft.)

The thermal conductance, C, may be written as: $C = \frac{KA}{L}$

For heat flow in parallel the combineed conductance is:

$$C = C_1 + C_2 + C_3 + \ldots + C_n$$

In case of series flow:

$$\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + \ldots + \frac{1}{C_n}$$

If the area for each process is the same, individual coefficients may be combined for parallel flow as:

$$U = h_1 + h_2 + h_3 + \ldots + h_n$$

and for series flow:

$$\frac{1}{U} = \frac{1}{h_1} + \frac{1}{h_2} + \frac{1}{h_3} + \ldots + \frac{1}{h_n}$$

In analyzing the flow to any one dryer, we would use the series flow equations and analyzing the flow to several dryers we would use the par-allel flow equations.

The conductance equation for series flow shows that the overall conductance cannot be greater than the smallest conductance in the series. As an illustration, assume a dryer with an overall conductance of 2000 BTU/sq.ft./hr. and also assume the following data for the shell:

$L = 1''$
$K = 300$ BTU /sq.ft./hr/in/°F
$t = 250 - 180 = 70°F$

then $U = 21{,}000$ BTU/sq.ft./hr.

From the series flow equation, the conductance for all parts of the dryer except the shell will be:

$$\frac{1}{2000} = \frac{1}{21{,}000} + \frac{1}{Ux}$$

and Ux = 2210 BTU/sq.ft./hr.

Changes in thickness or composition of the shell cannot do more than raise the overall coefficient to a value approaching U = 2210 as an upper limit. For example, assume that in the illustration above the conductance of the shell is doubled by some means (such as halving the shell thickness. By calculation U = 2100; or only a five per cent increase in heat transfer resulting from a 100 per cent increase in the heat transfer coefficient of the shell. Concerning this important principle, King *(1)* makes the following statement:

"Some engineers do not seem to appreciate that there is no advantage in increasing an individual coefficient which is already high when the overall coefficient is limited by another process in series with it."

Assuming such variables as velocity and temperature of air, and temperature of drying source be constant, the modern theory of drying holds that the drying cycle will be divided into two distinct stages, (1) constant rate period and (2) falling rate period. The constant rate period occurs while the material being dried is still very wet and continues so long as the surface remains thoroughly wet. Evaporation proceeds at a constant rate and the material tends to assume the temperature corresponding to the wet bulb temperature of the surrounding air. At a certain moisture content, known as the critical moisture content, water no longer comes to the surface as rapidly as it tends to evaporate. This initiates the start of the uniform falling rate of drying. As drying continues, the surface of the sheet becomes completely dry and the moisture in the interior portion of the sheet is evaporated and comes to the surface as vapor. This period of drying continues at a decreasing rate until the equilibrium moisture content is reached. For ordinary drying on the paper machine the average temperature of the sheet will be approximately 180 to 190 degrees Fahrenheit.

The critical moisture content for newsprint is in the range of 37 to 42 per cent *(4)* and for book paper from 23 to 29 per cent.

Some tests reported *(2)* on a festoon dryer show that when the sheet was relatively wet and with 300 degrees Fahrenheit air, the sheet temperature was exactly the same as the wet bulb temperature. At a low moisture content this was not true. For example, with 130 degrees Fahrenheit wet bulb and four to five per cent moisture content the sheet temperature was about 180 degrees.

These test results are not surprising. On the contrary, they are as would be expected based on theory. When air below saturation is brought into contact with water, there is a tendency for some of the water to vaporize and add to the moisture content of the air. If no heat is added from an outside source (which is the condition prevailing in a festoon dryer, neglecting the minor effect of radiation) the heat of vaporization will come from the water and the air. The process of evaporation will continue until the air is fully saturated.

A process of this nature is, by definition, an adiabatic one, and the final temperature that is reached is termed the temperature of adiabatic saturation *(3)*, which is almost identical with the wet bulb temperature.

Actually, the method of drying in a festoon dryer is very little different than that employed with a sling psychrometer, the only major difference being the substitution of a wet web of paper for the cotton wicking commonly used on the wet bulb thermometer.

If the temperature of the water is initially higher or lower than the initial wet bulb temperature, there will be a slight corresponding change in the final wet bulb temperature of the air. Actually the quantity of heat required to make even a fairly substantial change in the temperature of water is minor compared to the latent heat of vaporization. For most cases the difference in temperatures would not be over about 30 or 40 degrees, which is only about three or four per cent of the latent heat of vaporization.

In drying on the paper machine, where drying cylinders are used, the major source of heat for drying is from the dryers themselves and not from the air. The initial wet bulb temperature is of little importance since the process is no longer even approximately adiabatic. In this case, the sheet temperature tends to approach the wet bulb temperature of the surrounding air but it will always be greater due to the high rate of heat input from the dryers. As the sheet becomes drier, the amount of vapor generated will become insufficient to carry off all the heat input of the dryers and the sheet temperature will begin to rise. To prevent sheet temperature from becoming excessive, the last few dryers on a machine are often throttled. In all probability, the point at which the sheet temperature begins to rise will correspond with the beginning of the falling rate period of drying previously discussed.

The theory has been advanced that the temperature of vaporization will be that corresponding to the partial pressure of the vapor in the air space above the sheet. This, however, is an approximation which is nearly correct under fairly saturated conditions. Minton, one of those to advance this explanation *(5)*, was the inventor of the vacuum dryer. In a vacuum dryer the degree of saturation of the atmosphere surrounding the sheet will be quite high due to the small amount of air present. Under fully saturated conditions, the temperature corresponding to the partial pressure will be the same as both the wet and dry bulb temperature.

To check this theory for conditions less than saturation, the partial pressure must be found. The following formula *(3)* is convenient:

$$e = \frac{BW}{4353 + w}$$

Where: e = pressure of the water vapor, inches of Hg.
B = Barometric pressure, inches of Hg.
w = weight of water vapor, grains.

Assuming a dry bulb temperature of 150 degrees and 50 per cent saturation, by reference to a psychrometric chart *(22)*, w = 735 grains of water vapor per pound of dry air. Hence, e = 4.34 inches Hg and referring to steam tables *(24)* and interpolating, t = 128.3 degrees Fahrenheit; which compares closely with the wet bulb temperature of 130 degrees Fahrenheit. If the degree of saturation is 10 per cent, the saturation temperature will be 78.7 degrees as compared to a wet bulb of 93.6 degrees.

The importance of the vaporization temperature lies not so much in the amount of heat required for evaporation at that temperature, but in its effect on the rate of heat output of the dryers. For example, to raise one pound of water at an initial temperature of 100 degrees Fahrenheit to saturated vapor at 180 degrees Fahrenheit will require 1070.2 BTU's and to a temperature of 220 degrees Fahrenheit will require 1085.5 BTU's, a difference of only about 1½ per cent. The overall coefficient of heat transfer, however, will vary directly with the difference in temperature between the inside and outside of the dryer. Thus, when the temperature of evaporation is allowed a greater temperature differential exists with a consequent more rapid transfer of heat.

Enough has been said to indicate the importance of air in drying. One superlative will serve to point this up.

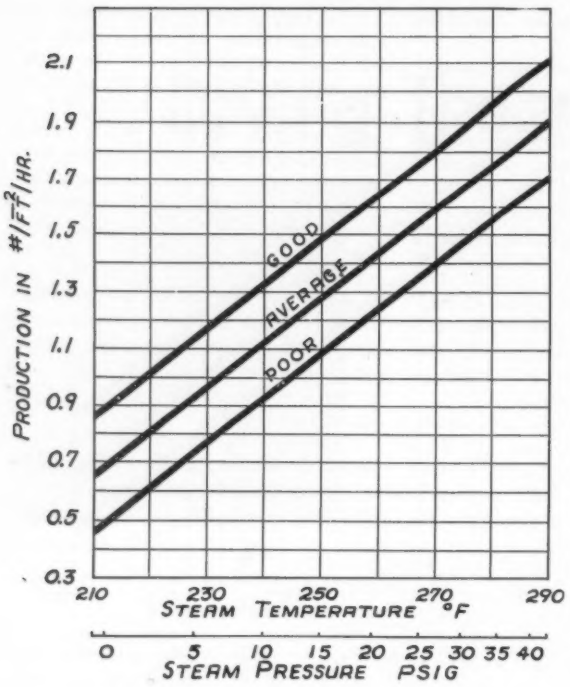

Figure 1—Production V.S. Steam Temperature for News Print

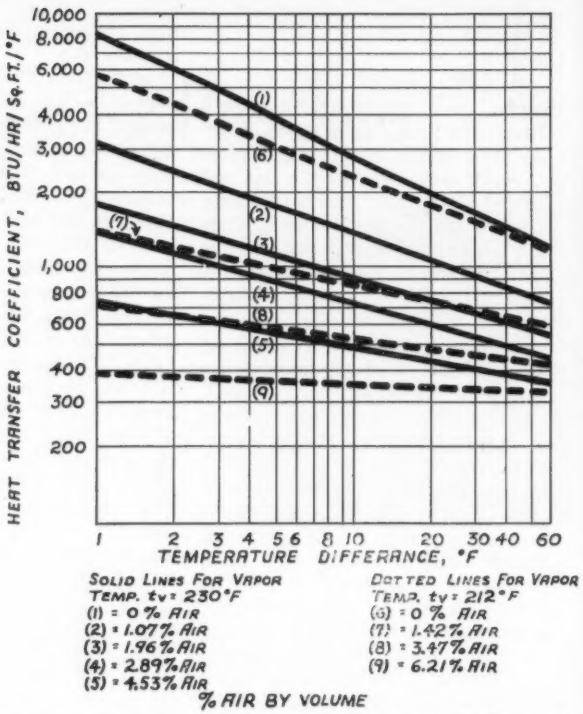

Figure 2—Effect of Air on Surface Coefficient . . . Coefficients for Steam Condensing on a Horizontal 3-inch Tube.

A recent advertisement by the J. O. Ross Engineering Corporation (who install most of the machine air systems in this country) reports on Macon Kraft Company's machine, "The Buccaneer." In one 24 hour period this machine produced 840 tons of Kraft board or about 70,000 pounds per hour, and in doing so consumed air at the rate of about 120 million cubic feet per hour. At a specific volume of 15 cubic feet per pound of air, this would represent eight million pounds, or 114 tons of air per ton of board produced.

These figures are not typical, many mills would be satisfied to produce 840 tons in a week. They do show that lack of mention of machine room air in the remainder of this paper is not intended to minimize its importance.

Factors Concerning Heat Transfer

The following factors are listed by O'Donoghue *(6)* as affecting dryer heat transfer:

1. Steam pressure in dryer.
2. Air in steam.
3. Water in dryer.
4. Coating on inside of dryer.
5. Coating on outside of dryer and rough surfacing.
6. Poor contact of sheet to dryer.
7. Thickness of shell and material used in construction of dryer.
8. Dryer contact area.
9. Temperature and moisture content of sheet.

To this Stamm *(7)* would add:

10. Circulation within the dryer.

1. Steam Pressure in Dryer

The trend in dryer pressures is upward in order to obtain higher drying rates. It may be necessary, however, to limit the drying rate over the first few dryers in order to prevent blowing, searing, cockles, case hardening, and too rapid shrinkage.

The relationship between steam pressure and drying rate is not satisfactorily known. *Figure 1* by Adams *(8)* shows that for newsprint the rate of drying varies directly with steam temperature. Unfortunately, this study does not go beyond approximately 40 pounds per square inch gauge steam pressure (the survey being made in 1933).

Figure 2 from King *(9)* shows an interesting relationship between surface coefficient and temperature differential. The coefficient decreases as the temperature increases due to the building up of the condensate film. While these curves are for steam condencing on a three inch tube, the principle is equally applicable to steam condensing in a dryer.

Referring again to this curve, we see that it is a straight line on a log-log paper; hence the form of the equation is:

$$h = (K\Theta) - x$$

where: K = a constant

Θ = temperature differential

Multiplying through by the temperature differential we find

$$h\Theta = U = (K\Theta)^{1-x}$$

It is logical to assume that:

$$\frac{R_1}{R_2} = \frac{U_1}{U_2} = \frac{K\Theta_1{}^{1-x}}{K\Theta_2{}^{1-x}}$$

Where R = drying rate.

If we let t_R represent receiver temperature, then:

$$\frac{R_1}{R_2} = \left[\frac{(t_1 - t_{R1})}{(t_2 - t_{R2})}\right]^{1-x}$$

The above equation is of the proper form to predict the effect on a given drying rate for a given change in steam temperature. The factor t_R in the equation may be interpreted as the equivalent sheet temperature for the entire dryer section.

Unfortunately, the factors x and t_R will not be constant but will vary depending on the dry and wet bulb temperatures of the air, steam temperature, quantity of air in the steam, efficiency of condensate removal system, and other variables.

Despite all of the many variables, it is interesting to note that this equation fits the data shown in Figure 1. Making the assumption that $t_{R1} = t_{R2}$ and fitting this equation to the average drying curve gives:

$$\frac{R_1}{R_2} = \left[\frac{(t_1 - 170)}{(t_2 - 170)}\right]^{0.95}$$

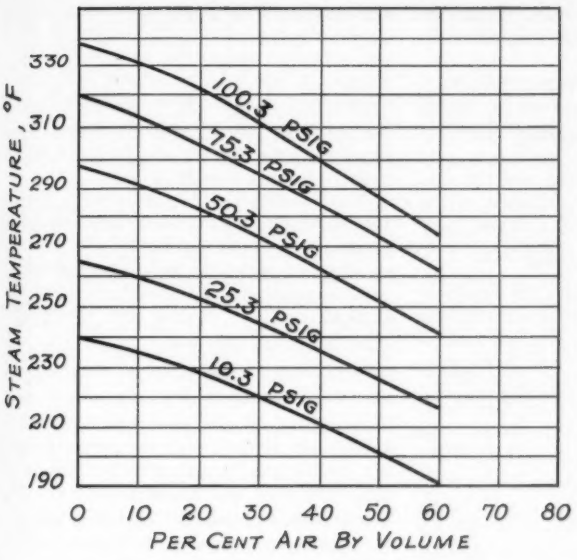

Figure 3—Effect of Air on Steam Temperature

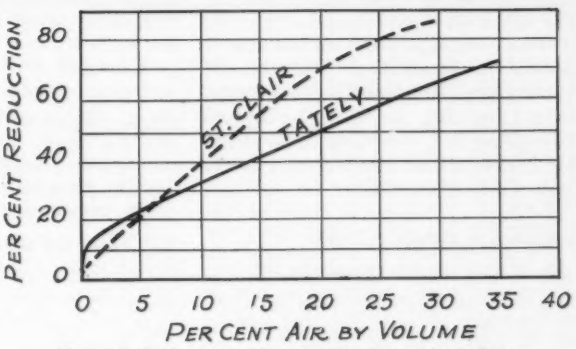

Figure 4—Reduction in Heat Transfer Due to Air in Steam

The average evaporation temperature of 170 degrees Fahrenheit found here agrees quite closely with the theoretical evaporation temperatures reported by Cowan *(28)*. According to this information the evaporation temperature would be 170 degrees Fahrenheit at a production speed of 900 feet per minute which is probably not far off the average speed for the drying data under consideration.

2. Air in Steam

Air and other non-condensable gases in the dryer will materially reduce the temperature and hence the heat transfer. O'Donoghue *(6)* mentions that the amount of noncondensable gases entering the dryers on a certain test varied between 0.0025 and 0.005 per cent by volume. Assuming the latter figure in a 48 x 100 inch dryer condensing 360 pounds per hour at 10 pounds per square inch gauge, this would mean 10 per cent air in about 36 hours, if no provision were made to eliminate it. From *Figures 3 and 4* this amount would reduce the steam temperature from 240 to 230 degrees Fahrenheit and decrease the overall coefficient of heat transfer 30 per cent.

Figure 3 shows the rapid drop in steam temperature for various increasing percentages of air by volume in steam *(6)*.

Figure 4 shows the per cent reduction to be expected in heat transfer for a given volume of air according to St. Clair and Tately. *(6)*.

The question of whether the air inside the dryer is thoroughly diffused in the steam or whether there is a chance for an air film to form is one open to debate. Tately, as reported by O'Donoghue *(6)*, took samples from an operating six foot diameter dryer with the following results. Three tests, two inches from the inside top of dryer shell averaged 2.29 per cent air by volume. Three tests, two inches from the inside bottom of dryer shell average 2.28 per cent air. Three tests at the middle of the dryer averaged 2.31 per cent air. These results would seem to show that the air is rather thoroughly diffused within the dryer.

In the discussion to O'Donoghue's paper *(6)*, Caldwell states that he has direct experimental evidences on condenser tubes that the drop in heat transfer is greater than would be indicated by the drop in temperature due to the air steam mixture. The only explanation is that a film of air does form at the surface. It does not seem possible that a band of practically pure air could exist at the inner surface of the dryer. However, it does seem entirely conceivable that an area relatively rich in air could exist. Tately's measurements were taken two inches from the shell. To be conclusive, his measurements would have had to be taken at about one eighth inch from the shell.

We may conclude then that an area immediately adjacent to the shell contains a relatively higher percentage of air than on the average and that this relatively rich air-vapor mixture does retard drying to a significant extent.

3. Water in Dryer

It is the function of the syphon piping or dipper piping in the dryer to evacuate the water. With fixed (drop) syphons there is a tendency for cycling to occur, that is, the end of the pipe becomes covered and draining starts and continues until the end is uncovered when evacuation stops, and so on. Almost all new machines built today are supplied with revolving syphons; however, most older dryers are equipped with drop syphons.

As mentioned in the previous section, air and other non-condensable gases in the dryers will seriously retard heat transfer. A small amount of these gases will become entrained in the condensate and will be drawn off with it. The only way to remove the larger part of it, however, is to bleed off a small amount of the steam noncondensable gases mixture and thus keep the concentration at a low level.

Since drop syphons depend on submergence for their action, they obviously draw off very little steam. Syphons which revolve with the dryer, however, do draw off steam; the actual amount depending upon the pressure differential across the dryer.

Traps also have an effect on the amount of condensate and air in the dryer. Years ago dryers were often equipped with a valve in the drop leg from the drver to the condensate header. The valve was periodically opened to blow out the accumulated condensate, then traps were installed to do this automatically. If the trap is properly sealed to prevent steam blowing off, then air accumulates in the dryer. Flash steam accumulating at the trap will cause vapor lock, making the trap inoperative until the trap cools sufficiently to condense the steam. To overcome these two faults, the traps were equipped with bypasses to continuously blow steam. We then reach the anomalous position of installing traps for the purposes of holding steam in the dryer, but at the same time carefully equipping the trap with a by-pass so that it can continuously blow steam.

The tendency today is to dispense with traps and use dryers with revolving syphons, depending on control of pressure differential to regulate the amount of blow through.

4. Coating on Inside of Dryer

The coating on the inside of a dryer

shell consists of rust, scale, and oil. The effect in retarding heat transfer of these coatings could be serious if allowed to accumulate. The thermal conductivity of boiler scale ranges from 1.2 to 60.0; for oil at 250 degrees Fahrenheit is 1.12 as compared to 310 for cast iron and 300 for steel at the same temperature *(10)*.

5. Coating on Outside of Dryer

A coating on the outside of the dryer has the same affect as a coating on the inside of the dryer. The coating on the outside of the dryer may consist of oil, rust, paper fibers, pitch, etc. To keep the dryers clean, many machines are equipped with doctors over all or a portion of the dryers. To prevent scoring, these doctors should oscillate.

6. Poor Contact of Sheet to Dryer

Air and vapor films between the sheet and the dryer will seriously affect drying. McNaughton *(11)* has shown that there is a good correlation between felt tension and drying rate on newsprint. Air has a conductivity at 250 degrees Fahrenheit of 0.523 and water vapor a thermal conductivity of 0.590, again as compared to cast iron with a conductivity of 310. The drying rate on a Yankee dryer is approximately three to four times as great as on an ordinary dryer, and may range up to as high as ten times as great *(12)*. This increased drying rate is due primarily to the intimate contact obtained by pressing the sheet firmly to the dryer by means of a pressure roll.

The view is occasionally taken that the felt acts as an insulator and tends to retard drying. Actually the felt, by making more intimate contact between the sheet and dryer possible, is a distinct aid in drying. Witness for example news machines where the first few bottom dryers are often not felted in order to retard heat transfer in the early drying stages. Trimbey *(27)* reports on some drying tests on a machine making wrapping paper. These tests were made both with and without a top dryer felt and showed that for the same speed, weight and per cent moisture in the paper going to the dryers, 10 pounds per square inch on the dryer header was necessary with the top dryer felt in use, and 15 pounds per square inch when the felt was removed.

It may be that with the same contact pressure sheet to dryer, with and without felts, that the felt might tend to hinder drying. This, however, is not a practical comparison since the pressure without a felt cannot be as high as with a felt, except perhaps on board machines. It is true, of course, that most heavy board machines do not use felts.

A smooth sheet of paper will have a higher drying rate than a rough sheet, due to more intimate sheet-to-dryer contact. Many southern machines are taking advantage of this fact by introducing a smoothing press about one-third down the dryer part.

7. Thickness and Material of Shell

Cast iron dryer shells predominate primarily because of ease of fabrication. Steel dryers have been fabricated and seem to be coming into more general use. The shell thickness for a steel dryer will be less than for a cast iron dryer at a given pressure, due primarily to the code requirement *(23)* of a safety factor of about 10 for cast iron versus about five for steel. Claims have been made of increased drying rates almost in proportion to the decrease in shell thickness. This ignores film coefficients which are of dominant importance.

8. Dryer Contact Area

On the usual four or five feet diameter dryer, contact area ranges between 50 and 66 per cent of the total area. A higher contact ratio is desirable but not obtainable, due to practical considerations such as accessibility for maintenance and ease of clearing a paper break. The contact on a Yankee dryer may exceed 75 per cent, which accounts, in part, for the high drying rates of such units.

9. Temperatures and Moisture Content of Sheet

The initial temperature of the sheet is relatively unimportant since the number of BTU's required to raise the sheet temperature to the saturation point is minor when compared to the number of BTU's required for evaporation. The effect of initial moisture content entering the dryer, however, is very important and much more important than many people realize.

Table I (13) shows the amount of water to be evaporated for a given initial and final moisture content. MacNaughton *(14)* has shown that on different newsprint machines the moisture content leaving the presses varied from 63.5 to 71.9 per cent. Referring to *Table I* at a final moisture content of 8 per cent, the water to be evaporated per ton, therefore, varied from 3040 up to 4550 pounds. Assuming 1.4 pounds of steam per pound of water evaporated, which is a practical minimum, the amount of steam required to dry this paper was 6370 pounds at 71.9 per cent and 4256 pounds at 63.5 per cent. The mill delivering its sheet from the presses at 71.9 per cent moisture content could, by decreasing this percentage to 63.5 per cent, increase its drying capacity in the order of 50 per cent. Actually, the rate would be somewhat less but still appreciable due to the fact that the more difficult falling rate period of drying would be obtained sooner with the lower moisture content from the presses.

MacNaughton *(11)* has shown that for newsprint a good average is 1.7 pounds of steam per pound of water evaporated. On this basis there would be a saving of 2570 pounds of steam, instead of 2114 pounds for the mill with the better pressing.

10. Circulation with the Dryer

Assuming an average dryer, the factor of circulation probably transcends all others in importance. The controlling effect of film coefficients has already been pointed out. Vigorous steam circulation combined with rapid evacuation of the condensate and non-condensable gases will greatly reduce these films, with consequent increase in heat transfer. The large overall coefficients found in heat exchangers is due in large part to the turbulent flow of water through the tubes.

Other Factors

The points briefly discussed above are among the most important factors affecting drying, however, there are others. For example, the size of the paper dryer has some bearing on the drying rate. For a given sheet tension, the smaller dryer would permit a larger unit pressure between the sheet and dryer surface than would a large dryer. Hence the intimacy of contact will be greater and, as has previously been discussed, the drying would be more efficient. Another factor in favor of the small dryer, not normally considered, is the relationship between head area and shell area. For example, on a 36 inch diameter by 140 inch face dryer, the head area is approximately 6.4 per cent of the total shell area whereas on a 60 inch diameter by 140 inch face dryer, the head area is 10.7 per cent of the total shell area. This means that more BTU's will be dissipated as heat loss through the head on the larger dryer than in the smaller dryer. One way to overcome this would be by insulating the heads; a comparatively simple process, but very few mills do this.

The efficiency of the felt dryers will also have a bearing on the efficiency of the main dryers. The purpose of the felt is, as previously noted, to hold the sheet firmly in contact with the dryer, as well as to actually support the sheet. Vapor which is generated on the dryer must pass through the felt. In doing so, some of it condenses

in the felt which makes it more difficult for succeeding vapor to pass through. The purpose of this felt dryer is to dry this moisture out of the felt and bring the felt to such temperature that appreciable condensation will not occur. If the felt dryers do not do this, drying will be retarded. Minton *(5)* has shown that on a vacuum dryer, where the temperature of the felt and of the vapor is the same, no felt dryers are needed since no condensation can occur in the felt.

Efficiency of the ventilating system will also materially affect the drying. The air system brings warm, dry air to the machine and carries away the moisture laden air. Certain variations of this system also prevent pockets of vapor from forming. Such pockets, by forming a blanket of very moist air, hinder drying. Also, if this vapor should be carried between the dryer and the sheet, it will hinder drying, more so than air, as has previously been shown.

Previous discussion on the theory of drying pointed out that there was a constant rate drying period followed by a falling rate drying period. The temperature at which the following rate period starts is known as the first critical point. A second critical point, occurring at a low moisture content, initiates a region where the drying rate begins to fall even more rapidly than before. With this in mind, we would expect that the amount of hydration would have some effect on the rate of drying paper.

Test *(15)* made on bleached sulfite at various freenesses have confirmed the existence of these two points. Also, the overall drying rate was lower for the slower stocks. However, the drying rates in the second and third phases were higher the slower stock, which tended to balance out the effect of the shift in critical points. The following table shows the time to dry a typical sheet from 60 to 4.75 per cent moisture content, versus the Williams freeness.

Freeness	Total time to dry in seconds
48	28.7
153	32.4
246	31.4
446	33.5
760	36.3
1380	26.0

Review of Drying Methods

The modern paper machine is an exceedingly expensive piece of equipment, and one of its most expensive components is the dryer section, not only from the point of view of first cost of the dryer section alone, but also when considering cost of the building to house the dryer section, maintenance, drives, and the power taken by these drives. On a typical machine the cost of the dryer section might run around 50 per cent of the total cost, exclusive of the building, hood and drainage system.

Some figures were previously presented for the Macon Kraft machine. On the day this machine produced 840 tons of paper, it consumed 263,000 pounds of steam per hour for drying and ventilating, and yet its 350 feet long dryer section accounted for only 1.24 per cent of the total quantity of water removed by the machine.

It is not surprising then that efforts have been made over a period of years to increase the efficiency of the dryers. When we speak of efficiency in this case, we mean pounds of paper dried per square foot of dryer surface. Hence, an increase in efficiency would mean less dryers to dry a given tonnage of paper. One way in which this efficiency has been increased is by increasing steam pressure and hence the temperature in the dryers.

A few years ago pressures of two and three pounds were typical; a pressure of as much as five pounds was considered pretty much the upper limit. The tendency now is to raise these pressures. On a contemporary dryer a pressure of 25 to 30 pounds per square inch gauge is considered low, 40 or 50 pounds is typical, pressures of 60 or 70 pounds are not unusual, and the tendency is towards even higher pressures of as much as 125 to 150 pounds, the upper code limit *(23)* for cast iron being 160 pounds per square inch gauge. In cast iron dryers, however, higher pressures tend to become somewhat dangerous and for these high pressures we may expect to see steel dryers coming more and more into use.

Drying at high temperatures has certain disadvantages on some sheets. On fine papers a high temperature may actually weaken the sheet, and on a highly sized sheet case hardening may develop which will hinder drying. To overcome these disadvantages, as well as to give certain other advantages, Ogden Minton *(5)* developed the vacuum dryer. In this drying system the entire dryer section is enclosed and placed under vacuum. Very substantial vacuums were used, as high as 28 inches of mercury. The rate of drying and thermal efficiency were independent of weather conditions as the paper was dried in a vacuum and not in the presence of air. Since the temperature of vaporization was considerably reduced, the amount of BTU's to evaporate a given amount of water was also reduced. Control of the drying rate was very simply obtained by regulating the pressure, which could be regulated to within two one-thousandths of an inch of mercury. Minton claimed he could reduce the number of dryers by at least 50 per cent with the installation of his system.

Several machines were equipped with vacuum dryers. However, the first cost of the system was high. Also, due to being enclosed, the dryers were not readily accessible for maintenance or for clearing a paper break. On a sized sheet it was found that vacuum drying was not satisfactory since higher temperatures were needed to set the size.

A great deal of interest has been aroused for electric heating, whether this be heating of the dryer or heating of the sheet directly. Primary interest has been shown for use of high frequency electronic heating as a supplement for ordinary steam dryer.

High frequency heating can be divided into two main groups: (1) heating by electro-magnetic induction, referred to as inductive heating, (2) heating by applied electro-static stresses in dielectric material, referred to as dielectric heating *(16)*. In inductive heating, the work is placed in the electro-magnetic field of a coil; the curent flowing through the coil induces electric curent in the work. These secondary currents produce heat in the work based on the law that $w = I^2R$, where

W = rate of heat generation in
I = current in amps
R = resistance in ohms

Inductive heating may find some application in the paper industry in the heating of the surface of dryers when temperatures above those available from low pressure steam are desired.

The dielectric type of heating is used for heating non-conductors such as paper. The work is placed in a strong electrostatic field produced by a high frequency voltage. Basically, two metallic plates are separated from each other by the material to be heated, and the plates, which form a capacitor, are connected to the terminals of a high frequency electronic generator. For a portion of the cycle one plate will be charged positively and the other negatively stressing the atoms of the intervening material in one direction due to the strong electrical field. A half cycle later, the polarities of the plates are reversed thereby reversing the molecular stress of the material. This continual reversing of the stress of the material causes friction between the molecules which manifests itself as heat. Without considering cost, this type of heating could be practical for thicker sheets such as paper board. However, on thin papers the resistance of the sheet would not be enough to

prevent arcing at any practical voltage level.

Concerning the use of electronic heating for paper, Nonken *(17)* makes the following statement:

> "Good as electronic heating may be, it is obvious that it cannot practically be applied to all heating problems. Therefore, each application should be made to stand on its own merits. For example, the problem of the drying of wet paper on a paper machine is one in which electronic heating may not be essentially better than the present method of heating by contact with hot rolls. Drying processes require free air circulation, over the surface of the piece to be dried. This constitutes a serious problem of drying paper by electronic heating where plates are necessary on each side of the sheet. It is evident that at present this is not a natural application of electronic heating; however, further developments may make it practical."

Radiant heat drying has been used *(18)*. A particular application of such heating is the installation of burners under the bottom dryers to increase the drying rate. This is a special application that seems valid for boosting the drying rate where space is limited.

O'Donoghue in the discussion to Hall's paper *(18)* presented some figures for an actual installation which showed that while the drying cost per ton of paper was higher with supplemental radiant heating, the increased production reduced the unit labor and manufacturing costs sufficiently to give a net cost per ton slightly less than without the radiant heating.

Ulm *(19)* reports his findings that under some typical conditions 4800 BTU of radiant heat energy was required to do the same work that 2500 BTU of steam energy would do. From this he concludes that the local cost of steam and electricity should determine the feasibility of a radiant heat installation.

It is important to match the infrared wave length to the absorption characteristics of the material to be heated. Materials which are opaque to visible light may be transparent to certain wave lengths of the infra-red, and visa versa. Broughton *(26)* has shown that a water film 1 mm. thick is almost completely transparent to infra-red with a wave length of about 800 millimicrons (1 millimicron $= 10^{-7}$ centimeters) but becomes almost completely opaque to wave lengths above approximately 2500 millimicrons. Unfortunately, the high temperature, and hence high intensity, heat sources emit a large portion of the ineffective short-wave lengths. For example, the water film under discussion will absorb about 99 percent of the radiation from a 700 degree Fahrenheit source but only about 60 per cent of the output from a 4000 degree Fahrenheit source. The 4000 degree Fahrenheit source on the other hand has a radiation intensity in the order of 800 times greater than the 700 degree Fahrenheit source.

Other methods of drying have been tried. Electric air immersion heaters and strip heaters have been installed in dryers. Such means have some application to special small rolls but are not economical for normal installations.

A class of dryer in common use today is the Air Dryer. The original Loft drying of paper, is of course, air drying. Loft drying is seldom used today except for money paper. The two basic types of air dryers in use today are the Festoon Dryer and the Flakt Dryer. In the Festoon arrangement the sheet is looped over sticks and carried through the dryer thus supported. Stick and loop marks are objectionable and the process is wasteful since the stick marks must be cut out and sent back to the beater. The process is seldom carried out on the paper machine. Normally it is used in conjunction with an off-machine coater. Being slow and expensive, the process is confined to special high grades.

Flakt dryers are used on grades which are to stiff or brittle to pass around dryer rolls. In this class fall wall board and hard board. It also has an application on weak sheets which require continuous support during the drying stage. In this case the sheet will be carried on wire mesh which gives ample support, at the same time allowing free passage of warm drying air.

In order to conserve space, Flakt dryers are built in three or five layers arranged one over the other. The sheet passes through one bank and then drops down to the next lower bank traveling in the opposite direction, and so on. These space conservation measures are particularly important on heavy wall boards ranging up to 500 points in thickness, and weighing as much as 750 to 1000 pounds per 1000 square foot.

The common method of heat generation is by steam but gas and electricity has been used. Modern air drying is done in several stages with heat exchangers installed between stages for preheating of the incoming air by the warm, moist outgoing air.

Conclusion

To this point we have discussed rather generally various types and methods of drying without being concerned with any mechanical detail. The balance of this discussion will deal with rotating steam heated dryers which constitutes by far the most important method of paper machine drying in use today.

PART II
Drying Practice

Dryers (Cylinders)

Generally speaking, two types of dryers are used on machines manufacturing pulp and paper. First, and the most widely used, which will be discussed in detail, are the cast iron dryers. The second type is the fabricated steel dryer which will be explained briefly later.

Cast Iron Dryers

These dryers consist of three individual sections; the shell and two heads, the tending (front) side head and the drying (back) side head. Each part is designed in accordance with the A.S.M.E. Unfired Pressure Vessel Code for the maximum specified operating pressure.

Upon completion, the assembled dryer is tested hydrostatically to twice the design pressure, and if approved, the dryer is coded and stamped.

Two test bars are made for each dryer shell casting, and for every accepted shell, one bar is given a chemical and tensile test to see that the casting meets our material standards. The second test bar is stored for future reference. The same procedure is used on dryer head casting with one exception, and that is that several heads will have the same two bars as a representative sample, the reason for this being that several heads are poured from one ladle, whereas only one shell is poured per ladle.

Most modern dryers are cast with 40,000 pounds per square inch tensile cast iron with a small amount of molybdenum added for machining purposes. The shells are cast oversize to allow for machining inside and out. For example, a 60 inch high pressure dryer shell would be cast approximately five-eighths inches over on the outside diameter and one-quarter inch under on the inside diameter. The shells are rough turned, bored and then assembled with the heads. After assembly the dryer is finish turned and ground to matching diameters for the machine in question. For a complete dryer section, the paper dryers are held within one sixty-fourth of an inch in circumference to insure proper draws through the section. All dryers

on modern machines are dynamically balanced for maximum machine speeds. They are balanced by removing some of the weights cast on the head for this purpose or by bolting weights to the inside dryer shell flange.

Yankee Dryers are used to produce "machine glazed" paper, creped tissue and wadding. They differ from other dryers in that they have a very high polish on the dryer surface. Yankee Dryers are made up to 12 fet in diameter in this country and with shell thicknesses up to two and one-half or three inches. On the larger sizes, hollow split center shafts are used. These hollow shafts are coupled in the middle and blanked off from each other. Steam is fed through one end of the shaft and distributed by nozzles placed circumferentially around the shaft at the coupling. Condensate is removed through the other half aided by dippers or siphons.

Steel Dryers

Both conventional dryers and Yankee dryers have been made of stel, and both types are constructed with double annular shells supported by spokes. The steam and condensate flow through the hollow spokes from the cross shaft, into which steam is fed through regular steam joints. The shells are spaced close together and vanes are used to guide the condensate to the outlet spokes. Other methods are used, but vanes are the most common way of collecting the condensate. Although the rate of heat transmission is about equal for both steel and cast iron (336 to 312 B.T.U./ hr./sq.ft./ F./in.), the greater strength allows a much thinner wall for equal pressures. Conventional dryers work satisfactorily when fabricated of steel, but when used as a "Yankee," difficulties arise when drying light sheets due to the difference in heat transfer through the welds that tend to mark the sheet. Also, when creping, the surface of a steel dryer scores easily, and therefore they are not recommended for this type of installation.

Several attempts have been made to plate or clad dryers with various types of metals, but none to date have proven commercially satisfactory.

Both the cast iron and the steel dryers are used as paper dryers or felt dryers. When used as felt dryers, they are driven by the felt tension and are installed either in the "run" or on the felt return run. If installed in the "run"; that is, at a point where the felt leaves the sheet, wraps the felt dryer, then immediately returns to the sheet, it is referred to as a Feeney dryer. If it is installed on the return run, it is called a felt dryer.

Occasionally a small cast iron dryer is connected to circulating water and is used as a sweat or cooling roll. This is usually done on the last dryer and the condensate formed on the outside moistens the sheet surface. This added moisture allows the calenders to impart a better pressing or ironing action on the sheet.

If a dryer is installed on a separate steam and condensate system immediately before the dryer section, it is called a receiving dryer. This dryer is normally a small dryer and is used in this position to preheat the sheet before going into the dryer section. Due to receiving the sheet in a wet, low temperature state, a large amount of steam is condensed in this dryer. For this reason flash steam from the other sections is used to supplv this dryer, with the condensate going directly to the hot well or condenser.

Dryer Felts

The primary function of a dryer felt is to carry the sheet through the dryer section. Felts are necessary on light sheets to carry the sheet and press it on the hot surface. Through the intermediate range, the use of felts varies from no felts, felts on the bottom dryers only or non-felted after dryer sections. On the heavy board and felt machines, felts are rarely used.

Although felts actually improve sheet contact and thereby increase the rate of heat transfer, they reduce the drying rate of the machine. Since the dryer felts are dried on the return run by felt dryers and circulated air, they contact the wet sheet in an absorbent state and promote the drying rate in this section. Toward the dry end the sheet loses moisture more rapidly than the felt, and thus, carrying more moisture, the felt retards drying in the latter section. Felts also tend to retard rapid changes in dryer temperatures and moisture content of the sheet due to their relatively great capacity to absorb heat and moisture as compared with the sheet. This ability of felts to absorb heat allows more even moisture regulation in the sheet leaving the dryers.

Heavy sheets run on machines without felts are usually water finished. In order to prevent excess moisture while calendering, these sheets are overdried, and the final moisture is partially controlled by the water boxes. These sheets are dried almost bone dry (bone dry to two per cent), which is much easier to regulate than the more common three per cent to six per cent content run on machines with felted dryer sections. To dry a sheet to a moisture content of two per cent or lower requires additional dryers that naturally show very low rates of evaporation. This is one of the reasons for the lower drying rates on some heavy board machines.

While the sheet is between the felt and dryer, it approaches within a very few degrees the operating temperature of the dryer surface. The liquid water in the sheet is heated to a temperature above the corresponding temperature of the vapor pressure in the surrounding air. When the sheet leaves the felt and dryer, the heat of vaporization is given off and the escape of vapor from both sides of the sheet is instantaneous. The major portion of evaporation takes place in the draws between dryers, with the heat of vaporization being supplied by the sheet itself.

Felts are usually made of wool, cotton and asbestos. Wool felts stretch and have a low vapor transmission. They are used on sheets that must not show felt marks and require a smooth surface. Although cotton felts have the best transmission properties and are the lowest in cost, they deteriorate due to burning at high temperatures. Asbestos maintains its porosity upon aging but it is weak alone; therefore, a mixture of 60 per cent cotton is added, giving a felt with satisfactory life and porosity.

Dryer felts are much stronger than press felts, being in the range of 300 pounds per inch to 60 or 70 pounds per inch. Variuos types, weights, thicknesses and strength characteristics are obtainable.

Due to the great length of dryer felts, an automatic stretcher must be provided to accommodate the changes in length of the felts upon relatively sudden wetting and drying. A 200 feet long felt will shrink at least four to six feet upon wetting, and in case of a break in the web, it will stretch a like amount in a very few minutes.

Dryer felts, unlike press felts, are seamed in various methods. New felts are installed by cutting the old felt at the seam and fastening the new felt to the old one. The machine is then turned over slowly and the new felt fed through while the old one is rolled up, preferably on the reel for ease of handling. In cases where a felt is torn off or being installed on a new machine, the machine must first be threaded properly with rope and then the felt pulled through.

Rope Carriers

On machines where it is not practical or possible to hand thread the web through the machine, a rope nip is used to carry through a tail before putting the full sheet on the machine. This is done on large and high tier dryer sections, heavy sheet machines, and high speed machines, for safer, faster and more positive feeding.

Two spliced endless ropes are used

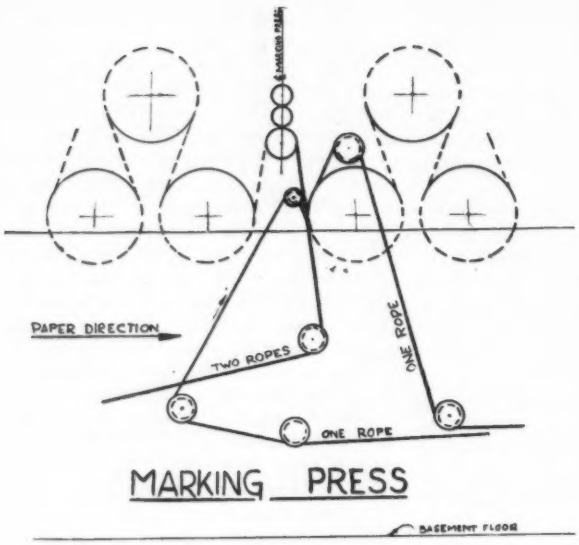

Figure 5

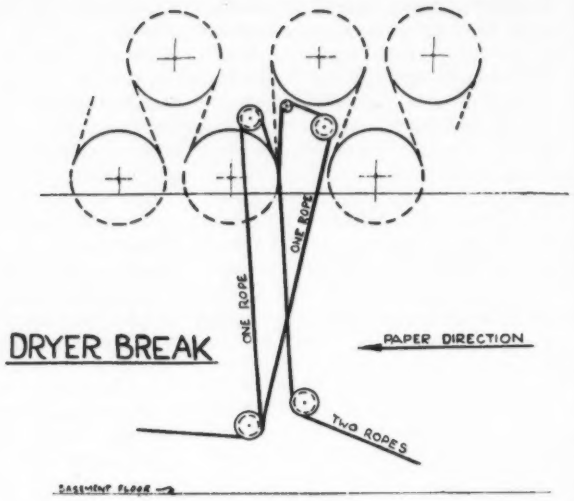

Figure 6

per section, and are driven at the sheet speed by rope sheaves attached to the revolving units. Free wheeling sheaves are used to support the ropes on the return runs and also to form up the nips.

Ropes are usually made of cotton or nylon and vary in size from one-quarter to one-half inch in diameter.

Figures 5 through 8 are four typical transfers. A transfer is the point where the sheet passes from one pair of ropes in one section into the next section's rope system automatically.

Bearings

Dryers are mounted on bronze or babbit plain bearings or anti-friction bearings. Plain bearings are very satisfactory on slow speed machines, and where cost is a factor they are frequently supplied on machines today. The principal difference in horse power requirements between anti-friction and plain bearings, within the operating range of plain bearings, is the break-away torque and at speeds below 200 feet pr minute. A plain bearing installation will require as much as two to four times the break-away torque required by anti-friction bearings.

Bearing loads are based on the total dryer weight plus the weight of water required to half fill the dryer. In this way the bearing will not be overloaded in case of a failure in the condensate removal system as the dryer can only half fill with water and above this level it runs out of the condensate pipe into the steam joint.

The driving (back) side bearings are held bearings, and the front side is free to allow for thermal expansion of the dryer. This movement is accomplished by mounting the bearing housings on either slides or rollers, or by pivoting on wedges, so as to have movement only in a direction lateral to the dryer axis.

Felt rolls are also carried in anti-friction bearings on all newer machines. On older type machines the felt rolls were mounted in full or half bronze sleeve bearings.

Three types of bearings are in use on paper machines today, the straight roller, tapered roller, and the spherical roller bearings. To adequately provide for misalignment the first two types of bearings must be specially mounted. Shown in *Figures 9 and 10* are typical

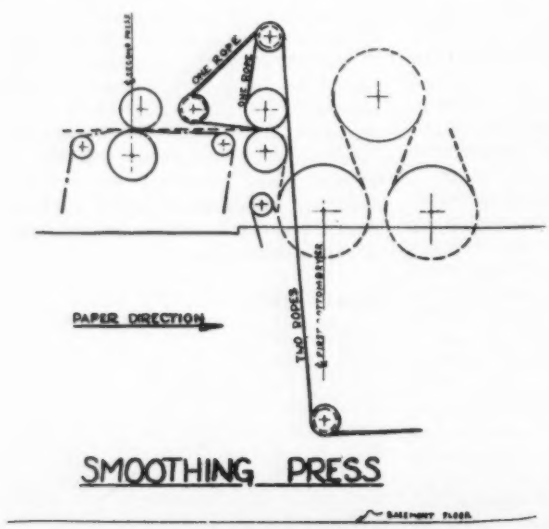

Figure 7

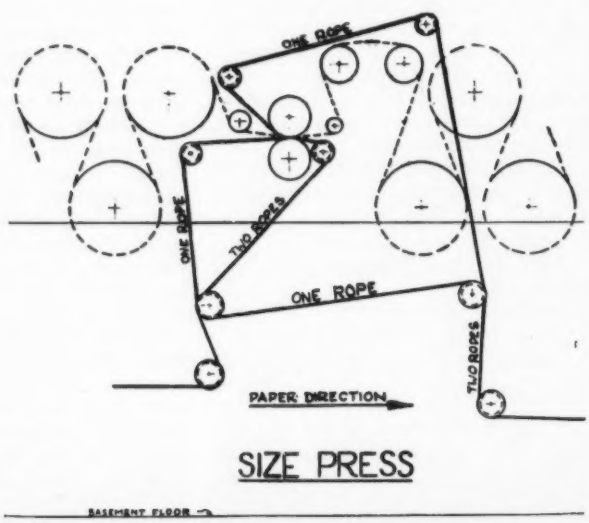

Figure 8

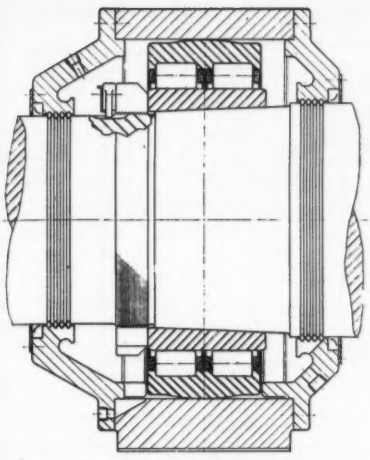

Figure 9—Straight Roller Bearing Arrangement

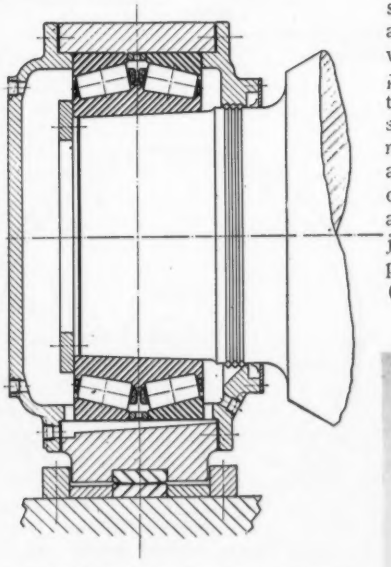

Figure 10—Taper Roller Bearing Arrangement

mountings for these bearings. A spherical roller bearing mounting is shown in *Figure 11*, for which no mounting alignment features are required.

Steam Joints(Fits)

Steam joints in principle are rotary seals used between the stationary steam and condcnsate piping, and the revolving dryer. There are two basic types, onc being for either steam supply or condensate removal, while the other type performs both functions in a single unit. Steam joints are normally installed on the driving side of the machine, feeding steam to the dryer through the driving side journal. Condensate removal is effected through a concentric pipe running through the journal to the rotary seal in the steam joint. With the single function units, one joint supplying steam is installed on one journal, and a condensate removal joint is used on the opposite journal. This type of installation is normally used on Yankee Dryers of large diameters. There are several types of steam joints on the market today. The main differences in the various joints are the manners in which pressure is applied to the rotary sealing surfaces and the type of surface used, either spherical or flat. Nearly all joints use a moulded carbon-graphite element against a ground metal seat. The joint may be of the pre-loaded spring type or a semi-balanced sylphon unit type. Both types of loading make satisfactory joints, only with the semi-balanced units less friction loads are encountered. *Figure 12* is a semi-balanced type of steam joint built by Pusey & Jones. The separate supporting bracket (A) is attached to the gear casing (B). The vertical steam piping (C) and water piping (D) are permanently connected to this bracket since it is not necessary to break these connections to remove the steam joint. This joint can also be removed while the machine is operating. Between the sleeve (E), attached to the extension of the dryer journal and the body (F) or stationary part of the steam joint, is a flat disc (G) made of carbon-graphite composition that requires no lubrication. A similar carbon-graphite disc (H), smaller in diameter, is located inside the body between a collar attached to the revolving syphon pipe (I) and the adjacent stationary member (J).

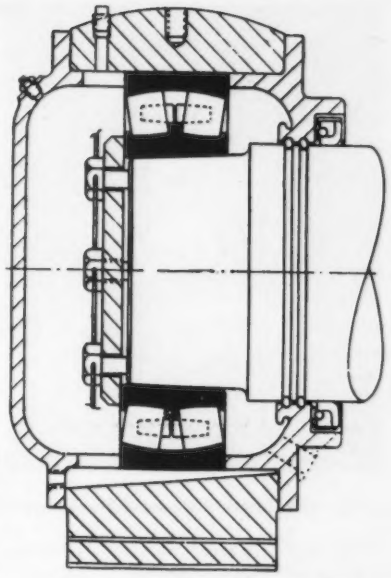

Figure 11—Spherical Roller Bearing Arrangement

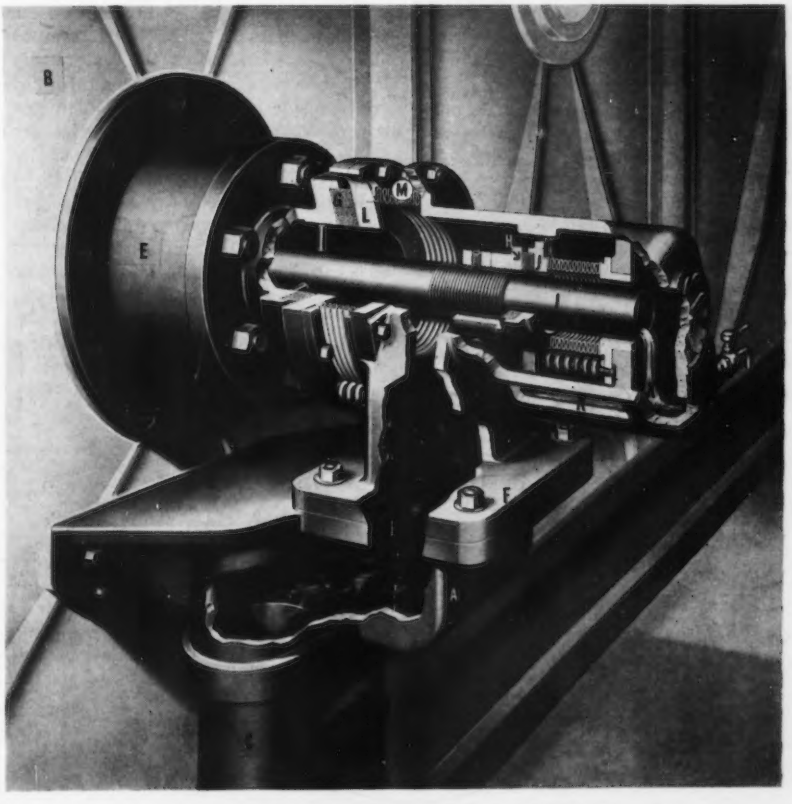

Figure 12—Semi-Balanced Sylphon Type Steam Joint

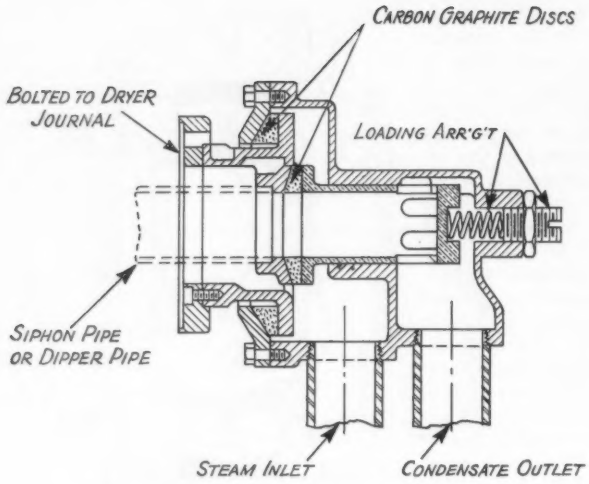

Figure 13—Pre-Loaded Spring-Type Steam Joint

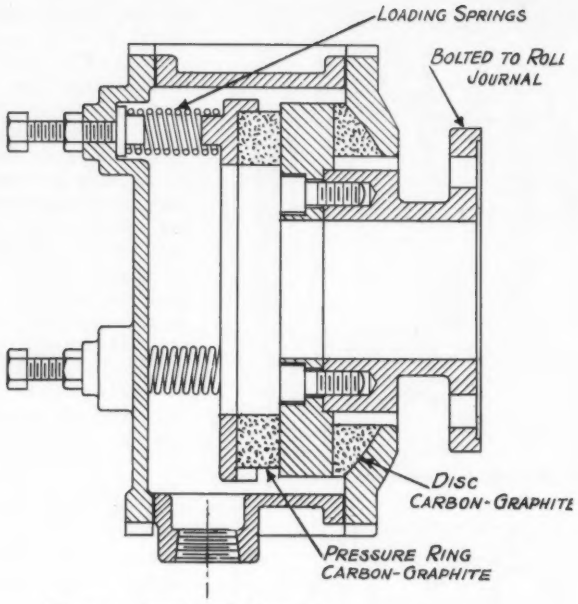

Figure 14—Single End Water Joint

The larger disc prevents steam from escaping to the atmosphere.

The smaller disc seals the interior steam space from the water compartment (K) into which the syphon pipe empties.

The flat surfaces of these discs, adjacent to the stationary part of the steam joint, bear against plates of a special close grain iron (J and L) highly polished to reduce friction. Plates are attached to the body by a sylphon unit (M) lightly loaded to reduce disc pressure to the minimum requirement for a perfect steam seal.

Shown in *Figure 13* is a spring loaded type of steam joint. This joint requires more horse power as it must be pre-loaded to assure contact pressure greater than that exerted by the maximum required steam pressure regardless of variable operating pressures. Shown in *Figure 14* is a water joint for use on sweat rolls and calenders.

Dippers and Syphons

Condensate removal is effected through either revolving dippers *(Figure 15)*, fixed syphons *(Figure 16)*, or revolving syphons *(Figure 17)*.

Revolving dippers *(Figure 15)* are troughs or scoops formed in an involute type of curve attached to the steam joint condensate removal pipe. These troughs or scoops revolve with the dryer and as they pass through the puddle of condensate at the dryer bottom the scoop or trough fills and discharges into the pipe as the dryer revolves. As you have no doubt surmised, this arrangement is only effective at slow speeds, for when the water rims it allows a constant steam blow through. It is considered that in 48 inch diameter dryers at speed less than 700 feet per minute condensate does not usually start to rim.

Fixed Syphons *(Figure 16)* are usually set a little past the bottom dead center line in the direction of rotation so as to operate in the deepest part of the puddle. A pressure differential sufficient to raise the condensate to the axial center line is required. Also, a steam trap in the discharge line is necessary to prevent blow through.

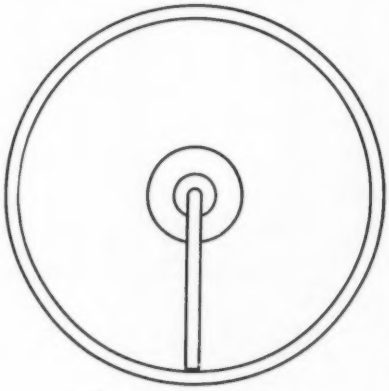

Figure 16—Fixed Syphon

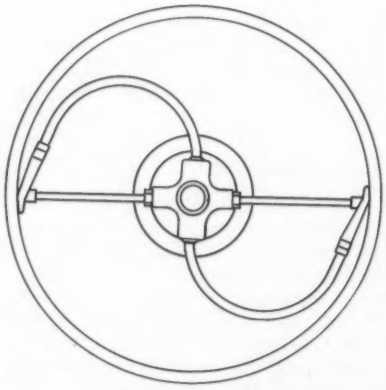

Figure 17—Revolving Syphon

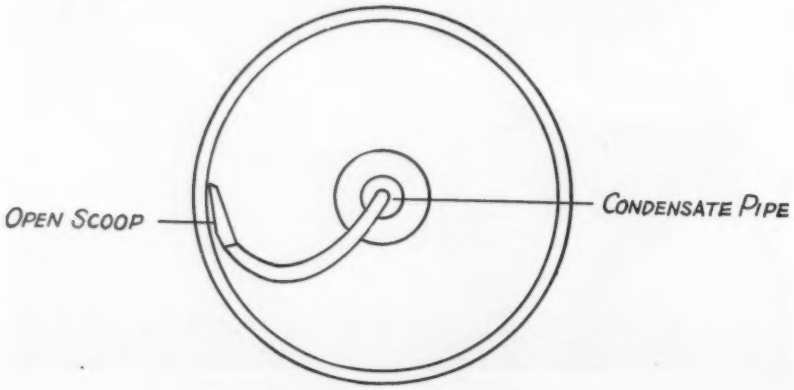

Figure 15—Revolving Dippers

Some mills today use a controlled blow through method and trap the condensate in a separator.

Revolving syphons *(Figure 17)*, have a close fitting scoop, and like the fixed

syphons require a pressure differential to operate. A greater differential is required with this type of removal system, as the centrifugal action on the water in the revolving pipes must be overcome. For example, in a 12 feet diameter dryer rotating 1300 feet per minute a centrifugal force of 2.2 pounds per square inch must be overcome and a pressure of 2.6 pounds per square inch is needed to lift the water to the steam joint outlet. (As the diameter decreases with the same paper speed the centrifugal force would increase.) This is a total pressure of 4.8 pounds per square inch, but in actual operation a differential of 2.5 to 3.0 pounds per square inch was sufficient for condensate removal. This is due to the reversal action of gravity when the pipe is in the upper half of travel. A small amount of blow through will assure the maximum removal of condensate.

Poor condensate removal can cause considerable power loss, and also overloads on bearings and dryer journals. Passing through the critical speed where rimming is imperfect the power surges are very high and can even cause gear failures.

Some of the effects of poor condensate removal are shown in the following charts, *Figures 18, 19, and 20.*

Ductors

Three types of ductors are used on dryer sections and they are as follows:

Cleaning Ductors: A metallic or plastic type of blade is used in a holder that is either self-loading or loaded. The pressure is in the range of three-fourths of a pound to three pounds per lineal inch. If loaded heavily, the ductor is quite frequently oscillated. Some of the plastic blades are formed of impregnated laminations, the grit varying from about 100 to 320. On the fine or higher grits, say 220 and up, the cleaning ductor is usually referred to as a polishing ductor. On cast iron surfaces an aluminum oxide abrasive is recommended.

Creping Ductors: These ductor holders are very rigid in construction with the blade supported in a flexible manner. The blades are made of various metals such as Swedish Saw Steel, Blue Steel, "K" Monel, and Bronze. The blade material depends on the type of crepe being produced, wet or dry. Blade pressures on creping installations may run as high as 20 pounds per lineal inch. The angle of contact measured from the tangential along with the blade thickness controls the fineness of crepe. These ductors must be supplied with a variable loading system and a quick release for blade changes. Some creping ductors are oscillated.

Cut-Off or Skinning Ductors: These ductors are used to peel the sheet off conventional dryers while feeding the sheet or during breaks. When used on Yankee Dryers it is used to strip off the sheet while changing blades on the creping ductor. By stripping the sheet off just above the creping ductor it maintains the surface temperature at operating level. If the sheet is removed from the Yankee the temperature will raise about 100 degrees Fahrenheit and may cause serious stresses. Also, due to over drying the sheet starts to blow. Metallic blades are used in these ductors.

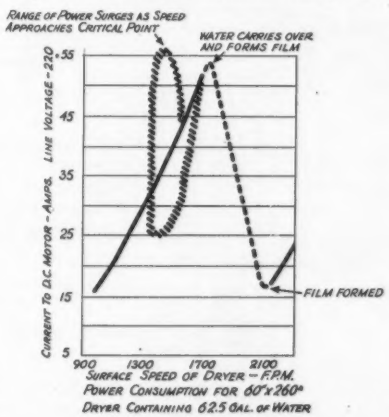

Figure 18—Power Surges Due to Poor Condensate Removal

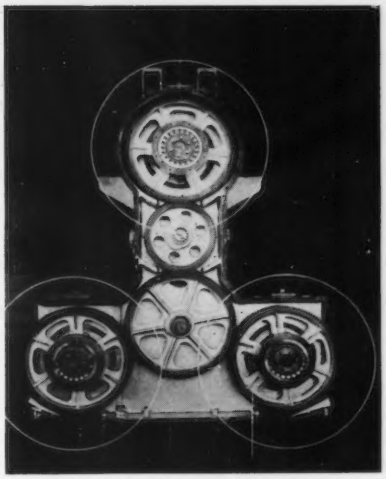

Figure 21—Typical High Speed Dryer Drive

Drives

The basic functions of any type of drive equipment follows the same pattern. A general list of the requirements are:

1. Motive power to drive the machine at maximum and minimum design speeds.
2. Sectional speed variation.
3. Inching and crawl speed.
4. An accurate and fine draw control.
5. Common machine speed adjustment.
6. Individual draw take-up momentary speed changes.
7. Ability to reverse calenders optional.

There are numerous ways, and combinations of ways, to drive machines and at this time no attempt will be made to cover them all. For purposes of general discussion the various types

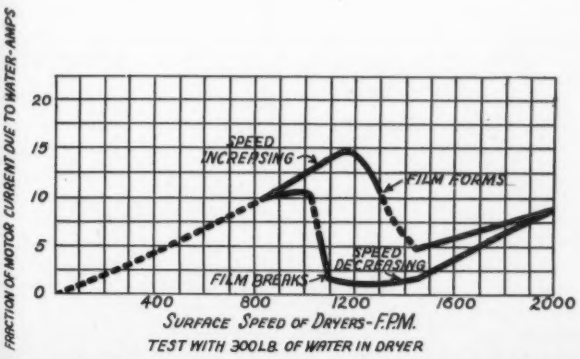

Figure 19—Effects of Water Rimming on Power with 300 lb. of Water

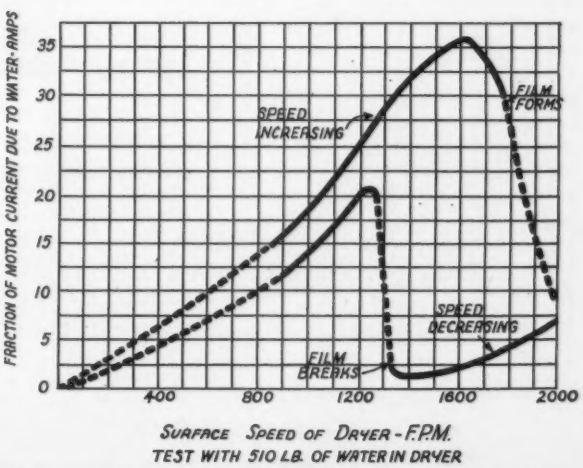

Figure 20—Effects of Water Rimming on Power with 510 lb. of Water

of drives can be broken down as follows:

1. Sectional electric drives.
2. Line shaft mechanical drives with either an electric or steam turbine prime mover.
3. Hydraulic variable speed drives.

A brief description of the three types of drives outlined above are:

1. Sectional Electric Drives

Two basic types of sectional drives are available.

A. Individual direct current motors deriving power from a single direct current generator driven by an alternating current synchronous motor, a steam turbine, or a combination.

B. Individual direct current motors deriving power from separately excited motor generators driven by a common prime mover.

In all cases some form of a regulator is used on each section motor.

2. Line Shaft Mechanical Drives

Two basic types of prime movers are used.

A. A direct current motor driven line shaft receiving its power from a motor generator set, or a turbine driven direct current generator.

B. A direct connected gear reduction type of steam turbine driving the line shaft.

Various ways of mechanically distributing the power from the line shaft to each section are used. A few of the types of mechanical take-off used are:

1. Cone pulleys and right angle gear boxes with either bevel or hypoid gears.
2. Cone pulleys and a combination of speed reducer and gear box.
3. Close coupled "V" belt driven variable speed right angle gear boxes.

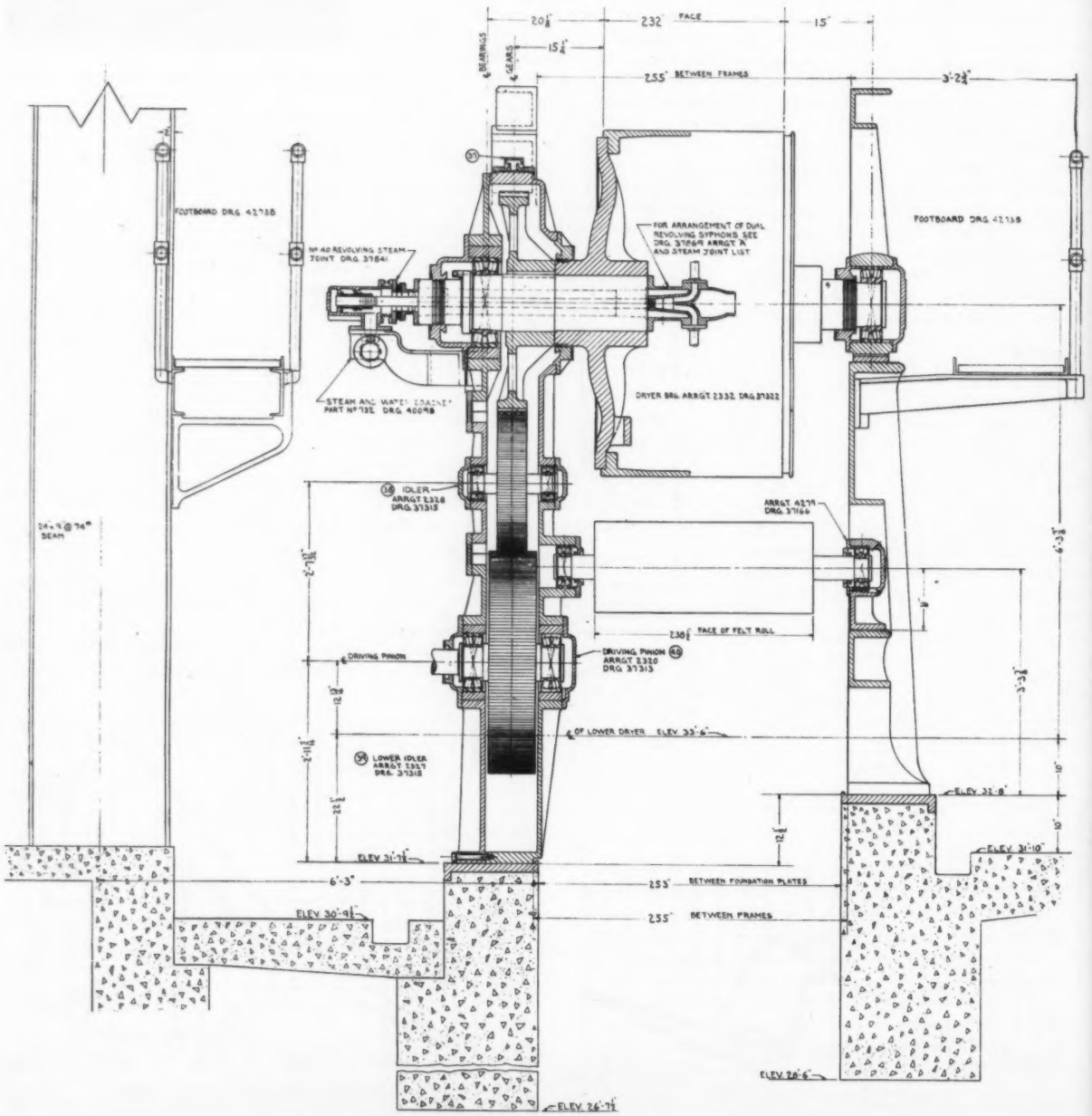

Figure 22—Dryer Cross-Section

Clutches are needed on the above installations for control purposes.

3. Hydraulic Variable Speed Drives

A common synchronous motor drives variable volume type pumps for each section. These pumps are coupled to hydraulic motors that drive the sections through speed reducers. Clutches are not required on this type of installation, as the pump volume is variable from maximum output to zero output.

The intake shafts on most sections are directly connected to the drive by flexible couplings, while on the dryer section the intake or intakes are extended pinion shafts driving the section through a gear train or chain drive. The conventional train for dryer sections operating up to 1000 feet per minute is the open type with spur gears. On machines operating over 1000 feet per minute it is recommended that totally enclosed, pressure lubricated helical gear trains be used. A typical high speed dryer drive is shown in *Figures 21 and 22.*

Mechanical drives are the most common in use today and are still widely used on new slower speed machines. On machines being built to operate over 1200 feet per minute electrical drives are highly recommended.

For high inertial sections, helper motors are geared into the section through a clutch and are used for inching, crawling and starting up. These motors are locked out when the section is taken over by the main drive which usually occurs around 150 to 200 feet per minute.

Maintenance cost on sectional electric drives average out lower on a horse power per year cost basis. Figures published by TAPPI on these costs are:

Section Electrical Drives:

Low 0.81 Average 1.98 High 3.12

Mechanical Drives with a Single Motor and Cone Pulleys:

Low 0.78 Average 2.25 High 4.70

The dryer drainage systems and vapor absorption systems that follow are explained in a very general manner, the reason for this being that both of these are separate parts of allied paper equipment manufacturing and are each individual fields of endeavor.

Vapor Absorption Systems

This is a system of controlled air supply and removal for the paper machine.

Supply air is usually drawn from outside through heating elements by fans and distributed to the machine. The points of distribution are usually on the return run of the bottom felts, onto the dryers or in a cross direction through the pockets formed between the dryers.

Removal is by a hood extending the length of the dryer section and suspend just above the machine. Fans exhausting to the atmosphere are connected to the hood.

Depending on the conditions of the ambient air and the building construction it is possible to increase the drying rates of machines as much as 15 to 20 per cent by a vapor absorption system.

One of the important points of these systems is the ingoing and outgoing air temperature control. The importance of of this can be seen by the example below:

	Temp.	% Sat.	Grains/Cu.Ft.
Supply Air	70 Deg. F.	70	6
Exhaust	130 " "	50	24
			Maximum Removal 18 Grains/cu.ft.
Supply Air	130 Deg. F.	12	6
Exhaust	170 " "	20	71
			Maximum Removal 65 Grains/cu.ft.

To remove 1000 pounds of water per minute would require with the unheated air $\frac{7000 \times 1000}{18}$ = 389,000 cu. ft. per minute, but with the heated air only $\frac{7000 \times 1000}{65}$ = 107,800 cu. ft. per minute would be required.

This reduction in motive power required, plus better working conditions, no condensate drip, and increased production rates, point out the advantages of installing a well engineered vapor absorption system.

Dryer Drainage Systems

The original systems, if the designation system can be applied to so crude an installation, consisted of a steam supply header and a condensate return header, that was allowed to blow freely to the boiler plant. Basically this system if kept clean of line blocks will dry as much paper as any other system as all essential conditions are met, with the exception of economy.

The next step was to install traps in various arrangements in the condensate lines. The problem encountered when using traps was to have a good system of air removal. Some systems using thermostatically operated air valves operated with fair results if a continuous discharge through the air vent needle valves was allowed.

Additions and changes over the years have been made to the systems until today a list of equipment used would include:

1. Traps-Float and thermostatically controlled with air bleeds.
2. Separators
3. Flash tanks
4. Thermo-compressors
5. Condensers
6. Vacuum pumps
7. Pressure controllers
8. Differential pressure controllers
9. Automatic control valves
10. Ejectors

A typical control system, as used by Midwest-Fulton, is shown in *Figure 23.*

Lubrication

Several methods of lubrication are used on the dryer section bearings. Two types of lubricants are used, either grease or oil, but the application of these lubricants varies greatly.

Grease—1. Block or bulk form of grease applied by journal contact, the grease being held in a box section on the unloaded side of the btaring.

2. Hand or power gun grease lubrication through fittings tapped in the housings.

3. Common rail with individual bearing tap lines supplied from a master power unit supplying grease at a predetermined interval.

Oil—1. Wick type of cap oilers.

2. Built in reservoirs with ring collar or chain feeders. (Plain Bearings).

3. Built in reservoirs with a level line for use with anti-friction bearings.

4. Cup type of drip oil feeders

5. Circulating oil feeder with flow regulators to each point of lubrication with a return oil system.

The modern circulating systems are composed of several sections. The oil is supplied to the bearings by an electrically driven pump. Gravity feed returns the oil to the supply reservoir. Before being recirculated the oil is cooled by a surface cooler, retained in a precipitation tank and filtered.

With a circulating system, as explained above, the temperature of the dryer bearings is lowered considerably over the other types of systems.

Felt rolls are usually lubricated by Tucker, Zerk or Alemite systems of gun lubrications.

Dryer Section Calculation

Basic Information.

1. Production Rate—400 Tons per 24 hrs.
2. Product-Kraft Paper—30 lbs. per 1000 sq. ft.

3. Sheet Width (to dryers)—200 inches.
4. Machine Speed—1200 F.P.M. (max.)
5. Steam Pressure—40 P.S.I.G.
6. Moisture to Dryers—37% dry.
7. Moisture to Reel—94% dry.
8. Dryer Diameter—60 in.

Dryer Surface—$\frac{60 \times \pi \times 200}{12} = \frac{262}{12}$ sq. per dryer

Hourly Production — $\frac{400 \times 2000}{24}$ = 33400 lb. per hr.

Water to be Removed—$\frac{33400 \times (94-1)}{37}$ = 51500 lb. water per hr.

Dryer Surface Req'd @ 2.8 lb. water per hr. per sq. ft. evaporation rate (TAPPI Evaporation Curve for 40 P.S.I.G. on Kraft Paper)

$\frac{51500}{2.8}$ = 18400 sq. ft.

No. of Dryers Requested—

$\frac{18400}{262}$ = 70.3 dryers

Evaporated Water to be Handled—51500 lb. per hr.

Condition of supply air—130 deg. F. @ 12% saturation*

Condition of exhaust air—170 deg. F. @ 50% saturation*

130 deg. F. @ 12% contains 6 grains water/cu. ft.

170 deg. F. @ 50% contains 71 grains water/cu. ft.

Maximum Pick-up 65 grains water/cu. ft.

$\frac{51500 \times 7000}{65} = 5{,}550{,}000$ cu. ft./hr.

$\frac{5{,}550{,}000}{60} = 92{,}500$ C.F.M.

*70 Deg. F. @ 70% Sat. air heated to 130 Deg. F.

Dryer Section Arrangement

Section #1	16	Paper Dryers
	6	Feeney Dryers
	2	Felt Dryers
Section #2	16	Paper Dryers
	4	Feeney Dryers
	2	Felt Dryers
Section #3	16	Paper Dryers
	2	Feeney Dryers
	2	Felt Dryers
Section #4	16	Paper Dryers
	2	Felt Dryers
Total Dryers	64	Paper Dryers
	12	Feeney Dryers
	8	Felt Dryers
	84	Dryers

Assuming a Feeney dryer equal to three-fourths of a paper dryer, this gives a theoretical total of 73 paper dryers.

Using the TAPPI Drive Standards, the H.P. requirements would be as follows:

Recommended Drive Capacity

200" face × .0027 HP/in./100 F.P.M. × 1200 F.P.M. = 6.48 HP/Dryer

Starting Torque = 2 × 6.48 = 13 HP/dryer

Section #1 = 24 × 13 = 312 HP

Section #2 = 22 × 13 = 286 HP

Section #3 = 20 × 13 = 260 HP

Section #4 = 18 × 13 = 234 HP

For plain bearings the above figures would be increased by 50%. Ductor Requirements = .00075 HP/in./100 F.P.M.

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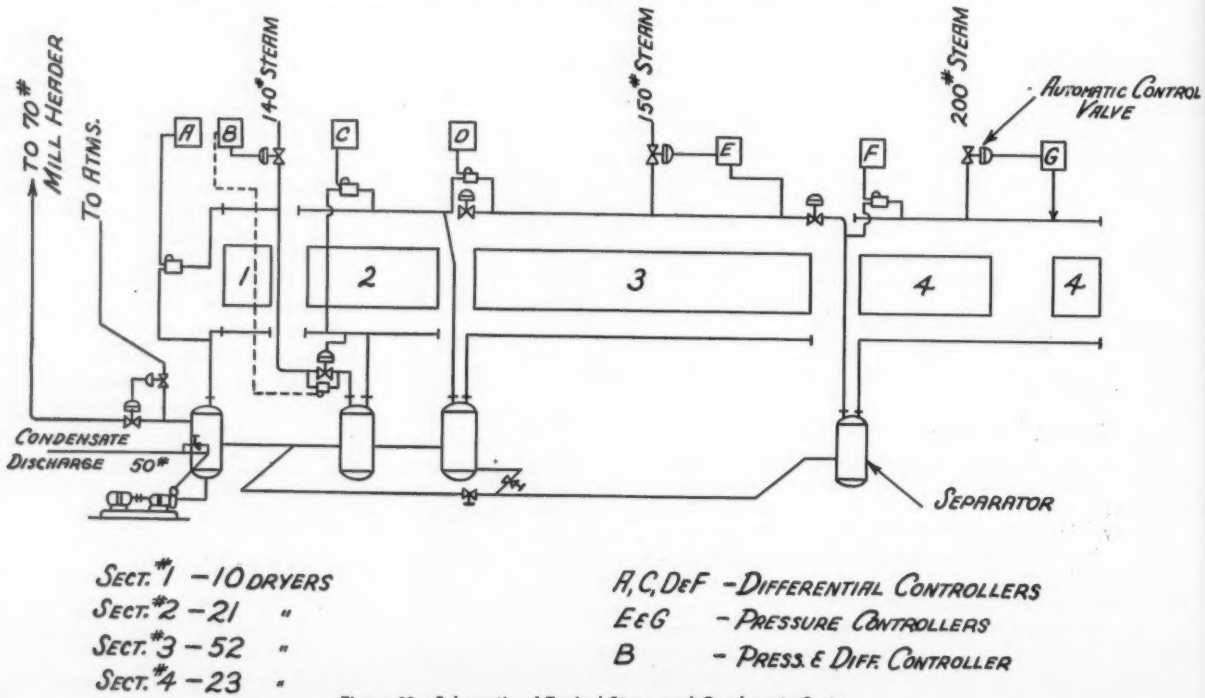

Figure 23—Schematic of Typical Steam and Condensate System

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Paper Coating

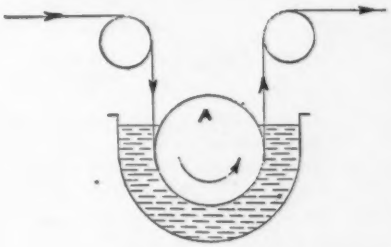
Harry G. Davis[1]

Introduction

The average paper maker is pretty apt to think of coating as a closely related step to the other operations involved in the manufacture of paper, and coated papers are being largely limited to clay-adhesive surfaced printing papers.

This was pretty much the case some fifty or more years ago, when coating was still in its infancy, but it is certainly no longer a true picture. Today, coating has grown into a vast, tremendously diversified industry, and in achieving this growth, a large, if not major, segment has become wholly divorced from the paper industry except as a customer of the paper maker. This growth has come about as a result of, and concurrently with, tremendous technological advances in the coating field. These are characterized by the development of a vast array of synthetics suitable for coating, and the development of products to utilize the characteristics of these new materials. At the same time development of coating methods and equipment have progressed at an equally impressive rate, particularly during the last two decades, so that today we have available coating equipment suitable for literally any of the new coating materials that have been developed. These developments in the equipment field are in part wholly new, in part borrowed from other fields, particularly from the printing industry. The effect of this borrowing has been the creating of a number of border line processes and products which can be classified as either, for example, coated or printed, coated or impregnated, etc. A similar confusion has arisen in connection with products which are surfaced with certain synthetics where the synthetic may be laid down on the base either by a conventional coating process from a solution, emulsion, or melt, or may optionally be laminated to the base. As a result of such overlapping, it is becoming increasingly common to consider purely decorative printing, impregnating, and laminating as parts of the overall coating picture.

It should be of some interest to this group to know that the growth of a coating industry that is independent of the paper industry has created a new, interesting, and rewarding field for men with a paper background. Most of the technical people in this industry are quite expert in their respeciive coating, but relatively few have any real background in, knowledge of, paper, paper making, converting machinery and processes, and coating machinery. This deficiency is freely recognized as a severe handicap, and is frequently magnified out of all relation to its real importance. Consequently, training and a general background in paper making is something of an "Open Sesame" in this industry.



CLASS 1 DIP COATER

Figure 1

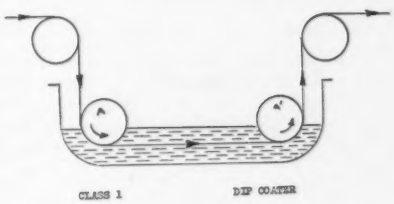
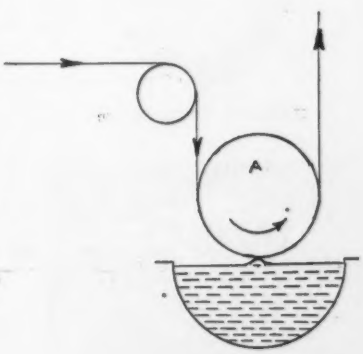


Figure 2



CLASS 1 DIP COATER
BEAD COATER

Figure 3

[1] General Superintendent, Oxford Paper Co., Rumford, Maine

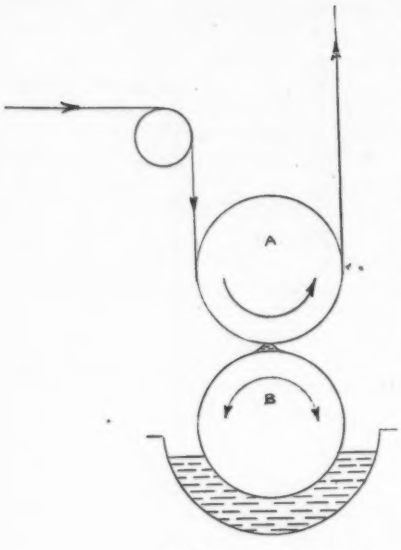


Figure 4

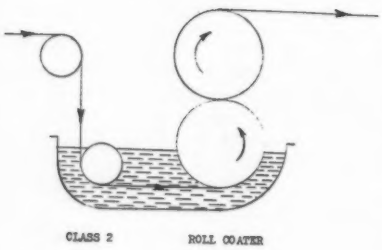


Figure 5

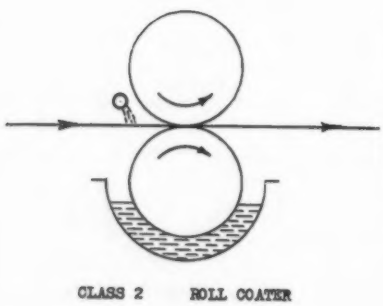


Figure 6

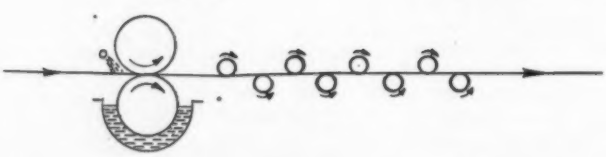


Figure 7

Coated Papers

Most coated papers can be grouped in one of three commonly used classifications of (1) Decorative, (2) Protective, and (3) Functional papers or coatings. Classification is not exact, inasmuch as many types of coated papers may fall into more than one classification. Wrapping paper, for example, is usually protective, but fancy wrappings are usually decorative and have very slight protective properties. Similarly, gummed tape is chiefly functional, but if it is dressed up with color, imprints, or similar decorations, it becomes both functional and decorative, while a waterproof gummed tape is both functional and protective.

1. Decorative

The term is self explanatory and is applied to coated papers which are used principally to beautify the objects to which they are applied, or to coatings which are applied to otherwise drab and rather unappetizing bases in order to enhance their appearance.

Possibly the most widely used and best known product in this category is Wall Paper, which commonly consists of a rather cheap base sheet, to one side of which is applied a clay-adhesive coating in order to improve the appearance of the base. This coating may or may not be made water resistant, or even water proof. The final decorative motif or pattern is applied by printing, using heavily pigmented inks having many of the characteristics of a coating color.

Paper draperies came out shortly before the war. These consist of a strong, long fibered paper base which is coated or impregnated with a coating that is heavily loaded with plasticizers such as glycerol and glycol. Again the pattern is introduced by printing.

Lamp shade stock may be coated or impregnated with mineral oil or synthetics for translucency, or with conventional pigmented colors for opacity. Either way, the desired end result is purely decorative.

The "Fancy" coated paper line is almost endless. Some of the more familiar items are Box Covers, Wrappings, Greetings and Shelf Papers. Most of these carry pigment-adhesive coatings.

Another highly diversified group comprises the Show Card line, which ranges from plain to highly decorated with metallic, mica, and floc coatings, and also fluorescent and phosporescent coatings. Display stocks are similar to Show Card. Again, pigment-adhesive coatings are most common.

2. Protective

This term is also self explanatory and implies that the coating or coated paper serves to protect the material to which it is applied from contamination or damage. The most familiar group of products in this classified are unquestionably the wrappers, such as waterproof, oil proof, grease proof, moisture vapor proof, and gas proof papers. Most of these are coated or impregnated in one form or another; some are laminated. Insect, mold, and rodent resisting paper gained wide use during the war.

Another very familiar group is the building papers, such as asphalt sheathing, asphalt shingles, roofing paper, and floor coverings. All of these are based on a heavy paper felt which is saturated with asphaltum, and then given subsequent treatment to convert it into the final end product, such as surfacing roofing with stone chips or mica, or coating and printing the wearing surface of flooring with oil or resin vehicle coating compositions.

By a little stretching of the imagination, we might consider that insulating board becomes a coated product when one side receives a coating of paint, and also does insulating siding when it is asphalt treated for waterproofing.

The so-called Artificial Leathers have been prominent for years, and are quite familiar to all as book covers. Some of the newer plastic materials in this category apparently have no connection with paper, as they are self supporting films. However, many of them are produced by coating the plastic on a highly finished paper base, which is subsequently stripped off and consequently does not appear in the finished product. This procedure is gaining favor in the production of vinyl coatings which are subsequently laminated to asphalt felt bases in the production of floor and wall coverings.

Rigid, so called Phenolic Sheets are now very common as counter and table tops, and are produced by impregnating a paper base sheet with the unpolymerized resin and curing with heat under pressure.

* most any product in most any industry can be made better with DOWICIDE "A"

Dowicide® A is water soluble and is, therefore, easily added to water extended adhesive solutions giving them protection from decomposition caused by mold and bacterial attacks.

Dowicide A is used effectively to disinfect contaminated walls before the application of a mold resistant paint. Water extensible paints are preserved with Dowicide A.

Dowicide A is used to disinfect buildings, egg storage rooms, and poultry feeding stations. When used in the wax emulsion coating, it protects citrus fruits from blue mold and stem-end rot.

In the paper industry, Dowicide A is used to protect paper sizing and coating solutions from mold and bacterial attack, both during use and storage.

Dowicide A protects soluble oil emulsions from bacterial decomposition and the accompanying unpleasant odors, emulsion breakdown, and the clogging of screens.

Rayon or silk thread in storage is protected against mildew by the addition of Dowicide A. It is also used to preserve protein, animal glue, casein and starch sizing solutions.

Water solutions of Dowicide A are used as disinfectants and germicides in public buildings and homes, and as a deodorant in and around garbage cans and chemical toilets.

Dowicide A prevents mold and bacterial growth during many stages of leather processing. It is also used to protect coating and finishing materials from costly bacterial attacks.

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DOW CHEMICALS

3. Functional

This term is commonly applied to coated papers on which the coating embodies special controlable properties that enables the composit product to be applied to purposes for which the uncoated paper is either totally unsuited or less suitable.

Since all papers, coated or uncoated, are functional to the extent that they serve useful purposes, the question of assigning coated papers to this classification is largely resolved by a process of simple elimination, i.e. if the primary usefullness of coated paper is neither Decorative or Protective, it must be Functional.

This classification thus becomes a catchall for a vast array of coated papers of extremely diversified characteristics, of which the following examples are representative:

Printing Papers. This group comprises the original coated papers, in which a pigment (clay, calcium carbonate, and others) and adhesive (casein or starch) mixture is coated on one or both sides of the base sheet with the twin objectives of improving the printability of the sheet through a smoother surface, better ink absorption, and improved optical characteristics, plus lowering the cost of the resultant sheet. The latter objective is attained in part through the generally lower cost on a unit weight basis of coating than of fibre, plus the ability to use somewhat less expensive fibre in the base sheet when these are hidden by the superimposed coating.

Included in this group are the coated, so called Book papers, used in the printing of magazines, books, pamphlets, brochures, etc., ranging in qualities from No. 1 (best) to No. 4 (cheapest), and with a variety of coating formulae to adapt the sheets to the individual requirements of various printing processes.

Coated Covers, except for the heavier basis weights, are similar to Coated Books, as are coated Card stocks.

Gummed Papers such as tapes and labels are coated with a variety of formulae, ranging from water soluble gums, dextrines, and glues to water insoluble synthetics having either pressure sealing or heat sealing characteristics. Many of these sheets, particularly in the label class, have the essential characteristics of coated one side Book, to the uncoated side of which the adhesive formulation is applied. Another product in this group, Fly Paper, is rapidly disappearing from the market, and it is perhaps interesting to note in passing that quite a few inventors have marketed scented papers coated with insecticides such as DDT, none of them particularly successful as insect killers.

Abrasive Papers are coated and marketed in a great variety of grades and forms, from the familiar sandpaper sheets to highly specialized abrasives on belt, disc, or drum bases. These are produced by first coating the base sheet with an appropriate binder, after which the abrasive grains are sprinkled on the still moist and tacky adhesive, oriented by electrostatic means, and rolled into firm contact with the base.

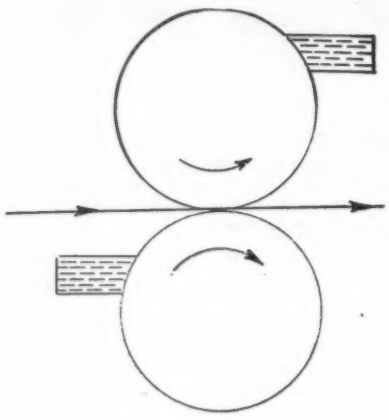
Reproduction Papers form the most diversified group in the Functional Paper classification. Among them we have the following typical examples:

Carbon Paper is coated with a molten wax-colored pigment formulation having the property of transferring or smearing to an adjacent surface when subjected to pressure.

In Hectograph Carbon, a very soluble dye replaces the pigment. The prepared carbon backs up a plain Hectograph Master, coated side toward the Master, and when the latter is typed, written or drawn upon, the carbon makes a reversed image on the back of the Master sheet. The carbon is peeled off, and if a plain sheet of paper is now moistened slightly with water or an alcohol mixture (spirit duplicator process) and squeezed into firm contact with the back of the Master, a portion of the dye in the reverse carbon image will transfer and produce a reproduction of the original image on the transfer sheets. This may be repeated until the dye in the carbon image is exhausted.

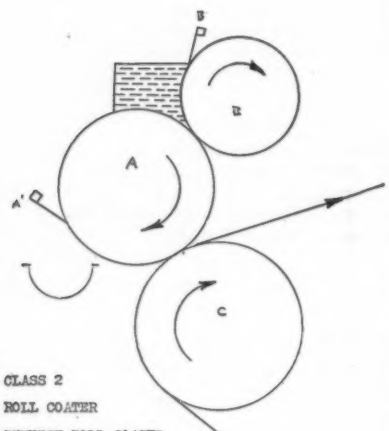
This process largely replaces the older Hectograph process, in which the original was typed, written, or drawn on plain paper with a special highly soluble dye based ink. This was then squeegeed into contact with moistened gelatin; some of the dye transferred to the gelatin, and when moistened plain paper was squeegeed into contact with the image bearing gelatin, another transfer of dye would take place, again resulting in a reproduction of the original. While this process is obsolete, gelatin coated papers (and cloths) are still being produced for use in this process.

The Mimeograph process is a stencil process, the masters for which consist of a special long fibre, very thin paper which is coated with a special wax formulation. When typed or written upon with a stylus, the wax coating is displaced, creating a porous area in the master through which ink will pass, and when the master is placed on



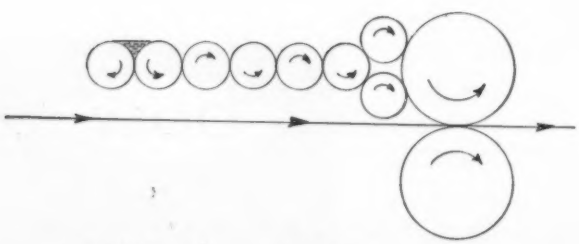
CLASS 2 ROLL COATER

Figure 8



CLASS 2
ROLL COATER
REVERSE ROLL COATER

Figure 9



CLASS 2 ROLL COATER
LETTERPRESS PRINT COATER

Figure 10

an inked pad and a piece of plain paper squeegeed into firm contact with the pad-master assembly, some of the ink in the pad is forced through the porous portions of the master to form an image on the paper.

Stencil papers and cards are coated or impregnated with a variety of proprietary formulae, ranging from waxes to varnishes, designed to make the stencil water and oil resistant.

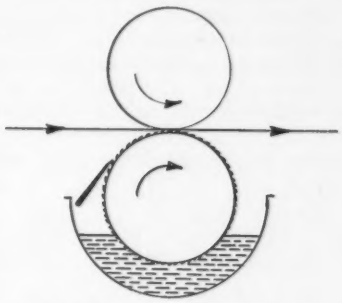
Lithographic Paper Printing Plates are becoming popular for short run printing, particularly in offices and institutions, and are based on the familiar principle of the Lithographers stone, which is wetable by either oil or water, but not by both. In other words, if such a stone is imaged with an oily or greasy ink and subsequently wetted with water, only the non imaged areas will pick up water, and if the wet stone is now inked with an oil base ink, only the imaged areas will pick up additional ink, while the water wetted areas remain clear. By squeegeeing paper into contact with the stone, a reversed inked image on the paper results. A rubber "blanket" may be squeegeed into contact with the stone to lift off the reversed image in the same manner, and if paper is then squeegeed into contact with the blanket, the image will transfer to the paper right side up. This is the so-called Lithographic (or Planographic) Offset printing process.

Quite a variety of materials, such as properly hardened gelatin, some of the higher alcohols, and many of the synthetics exhibit the same water-oil wetability characteristics to a greater or lesser degree as the lithographers stone. If such a material is coated on a paper base, the result is a printing plate which is so easy to handle that it may be used, and is for almost all reproduction purposes involving up to around 3,000 copies. Photo sensitive planographic printing plates are also being produced. Photo Sensitive Papers form a very large and extremely diversified group of reproduction papers, of which the three principle categories are Photographic papers, Blue Print papers, and White Print papers.

Photographic papers are based on the sensitivity of silver halides to light; an emulsion consisting of finely dispersed particles of the appropriate silver halides in a gelatin suspension is coated on a paper base. It sounds very simple, but since photographic papers are used to reproduce tonal gradations, and since even minute, down to the order of a fraction of a milimicron, variations in the thickness of the photographic emulsion results in corresponding changes in the rendition of such tonal gradations by affecting the "Contrast" of the paper, an extremely high order of precision is mandatory when such papers are coated. The sensitivity to light of the photographic emulsion is affected by contamination with even the most minute amounts of impurities, noteably iron, manganese, and copper, consequently, the base paper must be exceptionally pure. Most photographic paper bases are given a base coat consisting of several layers of Baryta in gelatin. The sheet is calendered after each layer has been applied and dried, and in this manner an absolutely level sheet is built up for the precision application of emulsion.

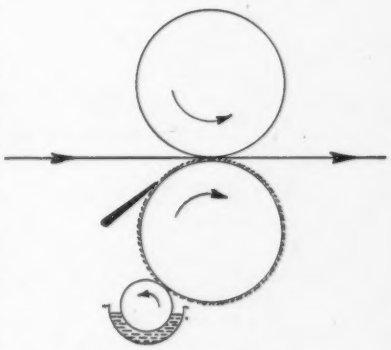
Blue Print papers are coated, or more properly speaking, the top surface of the base sheet is impregnated with a solution of a light sensitive iron salt, such as ferric ammonium oxalate, in water. Another ferric salt, such as potassium ferricyanide, in water solution is then applied, and the sheet dried. When such a paper is exposed to ultra violet light, the light sensitive ferric salt is reduced to its ferrous equivalent, and when the exposed Blue Print is moistened, the ferrous and ferric salts combine to form Prussian Blue in the areas which were affected by light, while no color forms in areas which were protected from light by, for example, lines, letters, or other opaque images in an original.

In both Photographic and Blue Print papers, a reproduction made by passing light through an original to the sensitive paper results in a negative image, as a solid color results only in those areas which were affected by light. White Print Papers, like Blue Print, are coated by surface impregnating the base with the light sensitive composition. In this case, the chemicals used consist of a light sensitive diazo salt, usually the metallic salt of a diazotized aromatic amine, a phenolic type of compound which, under alkaline conditions, will combine with the diazo salt to form an azo dye, and an



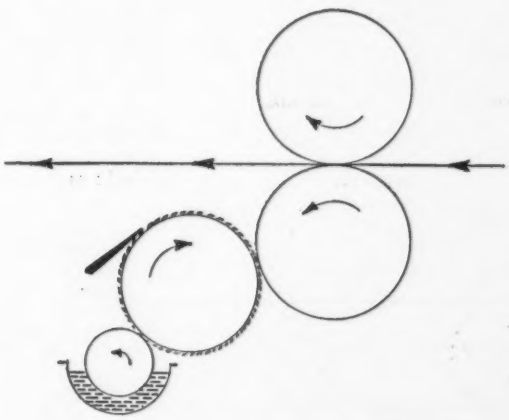
CLASS 2 ROLL COATER
ROTOGRAVURE PRINT COATER

Figure 11



CLASS 2 ROLL COATER
ROTOGRAVURE PRINT COATER

Figure 12



CLASS 2 ROLL COATER
ROTOGRAVURE OFFSET PRINT COATER

Figure 13

acid to prevent this combination from taking place. When such a paper is subjected to ultra-violet light, the diazonium compound is destroyed, and is no longer capable of forming a dye under any conditions. Consequently, when a reproduction is made by passing light through an original, only those portions of the White Print paper which are not acted upon by the light as a result of shading by the opaque image remain capable of forming a dye. This dye is developed by rendering the paper alkaline, such as by exposure to ammonia vapors, in which case a direct, positive, image of the original results.

Tracing Paper also falls in the Reproduction Paper group. One of the prime requisites of this paper is that it is to be as translucent as possible, not merely in order to enable the draftsman to see what he is tracing, but also to permit the making of Blue Prints or White Prints from the tracing. A normal sheet of paper is filled with voids, air spaces, and internal surfaces which tend to make the sheet opaque by scattering and deflecting light, particularly the ultra violet radiations which are commonly used in making reproductions as previously explained. If these voids are filled with a translucent material, such as, for example, mineral oil, the internal surface reflections are greatly reduced and the sheet becomes translucent. This principle is used in the production of tracing papers. A long fibered, strong, well formed light weight paper is impregnated with a suitable transparentizing medium, which may be mineral oil, a resin, or a synthetic.

These are a very few typical examples of coated papers, enough, perhaps to justify the contention that coating is a tremendously diversified industry having relatively little direct connection with paper making.

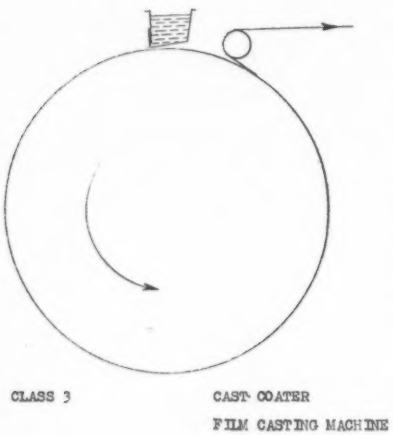


Figure 14

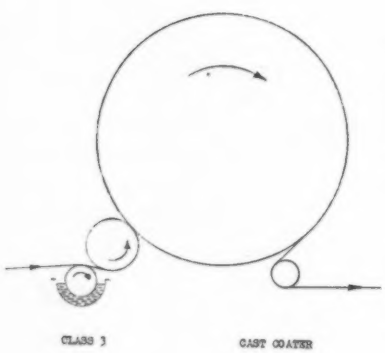


Figure 16

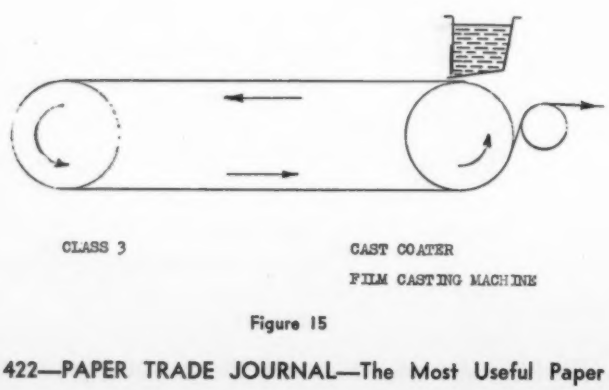


Figure 15

Coating Processes

It is hardly any easier to classify the various coating methods into related groups than the similarly classified coated papers, and the problem has become increasingly acute in recent years due to the combining of several basic methods, or elements of these, into new methods.

According to one of the earliest authors who attempted such a classification, there are only two ways to apply a coating to paper; you either roll it on, or you trowel it on. This was quite an oversimplification because he forgot that you could also flow it on, and you could spray it on.

A decade ago, Mr. Frank Egan published a survey of coating methods that is still the best study of its kind that has ever been made. It has been widely copied, and I will copy it here today and bring into it a few newer things that Mr. Egan did not include in his original study. Mr. Egan's study, with few modifications is incorporated in his contribution to the TAPPI Monograph on "Machinery for Paper Coating."

In this study, Mr. Egan concluded that there are ten basic methods of coating paper. In a later paper, Mr. Peter J. Massey, inventor of the first successful paper machine coating process, concluded that there were only seven basic methods. The principal difference in the analyses made by these two authors was Egan's separation of Roll Coaters and Print Roll Coaters, of Cast Coaters and Strip Coaters, and of Knife Coaters and Air Knife Coaters. In each case, with the possible exception of the last pair, the principles involved are, on the whole, so similar that classification is next to impossible in many instances. In the case of the Knife and Air Knife Coaters, the principle is very similar although the execution is radically different.

On the whole, I agree with Massey's view that there are seven basic methods, and applying these to Egan's survey, we have the following basic methods, with examples of each.

1. Dip Coaters

As the term implies, the coating is applied to the sheet by dipping the web into a pan of color. The dipping may either be a complete submergence of the web, or the web may be brought into kiss contact with the surface of the coating, in which case only one side of the web is coated. In any event, no further treatment is given to the coating on the web after the coated web leaves the color pan.

Figure 1 illustrates what is probably the simplest example of this type of coater. The web is led around the partly or wholly submerged dip roll A, and in doing, picks up a film of coating.

Figure 2 shows the same type of machine, but with two dip rolls A and A′ and a longer color pan.

Both of these coaters are used for impregnating or saturating webs, and have no use for applying surface coatings. However, by lowering the level of the coating color in pan of the apparatus shown in *Figure 2*, the web may be made to float on the surface of the color, in which case a coating of sorts can be applied at low speeds.

This may also be done to the arrangement shown in *Figure 1*, but only workably if a "bead" of coating is

established between the web and color surfaces by bringing the two into contact and then separating them slightly. This bead formation may be illustrated by wetting the thumb and forefinger, pressing the two together and separating them slightly, in which case it will be found that the gap between the two fingers is bridged by a bead of moisture. *Figure 3* shows a simple Bead Coater that is widely used in the coating of photographic materials. This apparatus is capable of extremely close control over the thickness of the film of coating that is laid down, provided that adequate provisions are made to control the level of color in the color pan with the highest precision, that absolutely no vibrations are present in either the stationary or rotating parts of the coater, and that the web travel is absolutely uniform and free from flutter and jerkiness. The machine can only be operated at relatively low speeds and with a low solides, low viscosity color, so it is only used where no other coating method will give the required precision. In addition, dip roll A must be slightly narrower than the web in order to avoid wetting it with color, and must be changed every time the web width is changed. Since this roll is usually loaded with a direct connected heavy flywheel or other dampening means, such a roll change can be quite involved. *Figure 4* shows a different arrangement of the Bead Coater, in which the bead is formed between the web and a Color Roll, B. This arrangement has the advantage over that shown in *Figure 3* in that the extreme precision control over the level of color in the color pan is not mandatory; otherwise the requirements and limitations of the two coaters are identical.

2. Roll Coaters

The essential principle of all roll coaters is a metering of the amount of color, either prior to or following application to the web, by passage through a nip or nips between adjacent rolls.

Figure 5 shows a simple arrangement of this type that is widely used as a saturator, waxer, and size press, in which the web passes through a bath of the coating color and thence through a pair of squeeze rolls which limit the amount of color to that absorbed by the web and/or that which will pass through the nip with the web.

In *Figure 6,* the web is conducted straight through the nip between the two squeeze rolls, and the color is applied in excess to the top side of the sheet through a sprinkler. The overflow color from the top side runs into the color pan, and the partially submerged lower squeeze roll picks up this color and applies it to the under side of the web.

Figure 7 is a refinement of the arrangement shown in *Figure 6,* in that a series of smoothing rolls have been added to spread and even out the coating after it has been applied to the web. When the sheet leaves the nip between the squeeze rolls the coating has a tendency to follow both the rolls and the web, and becomes badly disarranged in the form of gobs and streaks which take a fairly well defined, course pattern commonly known as "tracks" or "cat tracks." The smoothing rolls shown in *Figure 7* are small diameter rolls traveling at high speed in a direction opposite to that of the travel of the web. Each roll picks up a portion of the coating on the web, track pattern and all, and redeposits it on the web, but because of the very large speed differential between the web and the rolls, the redeposited pattern is very much finer than the original pattern, and by repeating this pickup and redeposit a sufficient number of times, the pattern becomes so fine that it is no longer discernible.

All of the coaters discussed so far have utilized coating pans in which either one or more coating rolls, or the web, or both are partially submerged. It sometimes happens that mechanical considerations make the use of such a dip pan unfeasible, in which case the so called "water box" type of color pans shown in *Figure 8* are used. These are simply open troughs with one side removed. The box on this open side is carefully fitted to follow the contour of the circumference of its mating roll, usually by means of suitable low friction sealing material in order to avoid scoring of the roll. As the roll rotates, it picks up coating from the water box and applies it to the web at the nip in the conventional manner. The arrangement shown in *Figure 8* is commonly used on calender stacks to apply water or starch solutions to paper or board coming off the paper machine when a regular tubsizing installation is not available for this purpose.

The Reverse Roll Coater shown in *Figure 9* combines some of the features shown in *Figures 5 and 6,* in *Figure 7,* and in *Figure 8.* The coating color is held in a modified water box, from which it is picked up by Color Roll A, which forms the bottom of he box. The amount of color carried by roll A is precisely controlled by the nip opening between this roll and Metering Roll B, which forms one side of the water box. Metering Roll B travels in a direction opposite to that of roll A, and is kept dry and clean by means of a scraper, or doctor, B′. In this manner, a uniform film of coating, quite free from "tracks," is laid down on roll A. The web is conducted around Backing Roll C, and the coating is applied in the nip between rolls A and C. However, at this point the two rolls are traveling in opposite directions and consequently, the coating is further smoothed and evened out

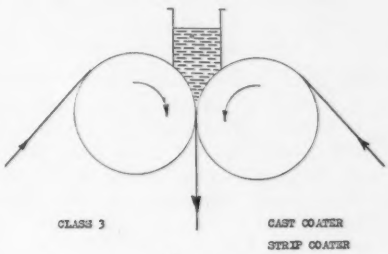


Figure 17

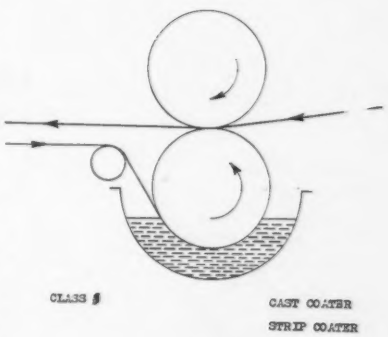


Figure 18

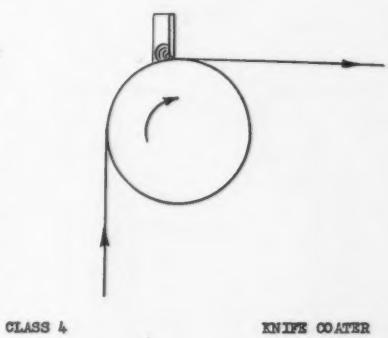


Figure 19

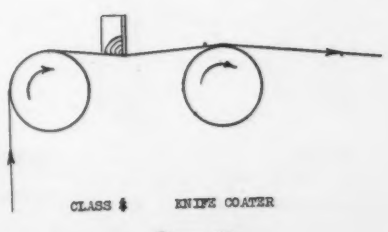


Figure 20

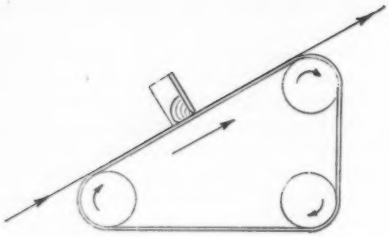


Figure 21

as it is applied to the web. Roll A is kept clean by means of a scraper, or doctor, A′, to remove any lint or dirt which the roll may have picked up from the web, and which would contaminate the color in the water box.

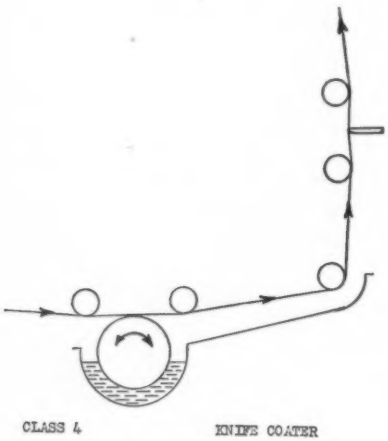


Figure 23

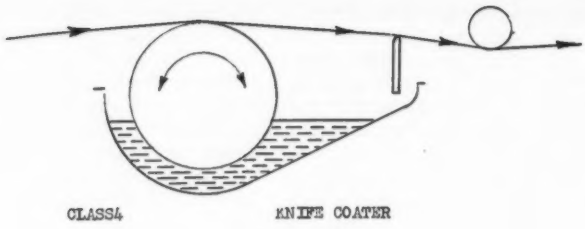


Figure 22

Figure 10 shows a coater which is largely patterned after the inking system on a letterpress printing press. Only the color system for the top squeeze roll is shown, but this is normally duplicated for the bottom roll as well. The color is held in a water box type of color pan, is metered by means of a metering roll, and is then transferred over a succession of distributing rolls which travel at different surface speeds, thus distributing the color into an even film which is finally transferred to the squeeze roll and thence to the web. Tracking at the squeeze rolls is avoided by a combination of specially selected roll cover and a special coating formulation featuring a very high solids content.

The coater shown in *Figure 11* is patterned after the rotogravure printing press, in which the printing roller is engraved with a series of shallow, minute cavities, each of which acts like a miniature color bucket. When the web is pressed into contact with the engraved roll, the color lifts out of each cavity and is transferred to the sheet in the form of minute dots which, if the coating is sufficiently fluid, flow together into a uniform film of coating. A doctor is used to keep the surface of the roll free of color, so that the only color carried to the sheet is that held in the roll cavities.

A modification of this coater is shown in *Figure 12,* in which the color is applied to the engraved roll by means of a color roll.

Both of the above arrangements can only be used for coating one side of the web at a time. *Figure 13* shows an arrangement by which the rotogravure coater may be used for coating both sides simultaneously (only one side application is shown). In this case, the engraved roll transfers the coating to an offset roller, where the dots run together to form a uniform film more readily than they do on the web, and this roll in turn applies the coating to the web.

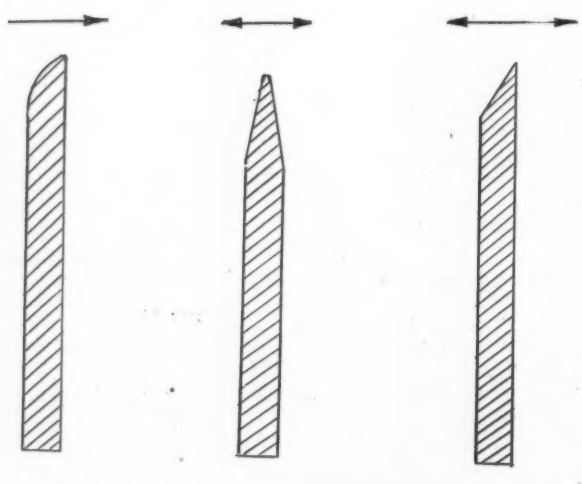


Figure 24

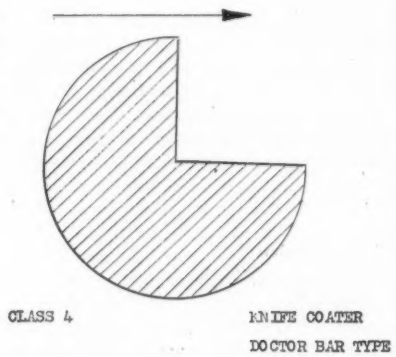


Figure 25

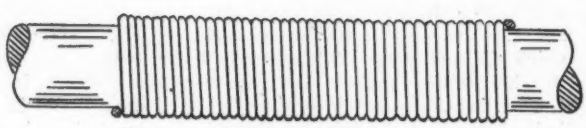


Figure 26

3. Cast Coaters

All cast coaters have the common feature that the wet coating is dried in contact with a surface whose physical characteristics are precisely reproduced in the resultant dried film coating. In other words, the coating is moulded into its desired shape.

Figure 14 shows a machine used for casting self supporting films, such as cellulose acetate or nitrate. The dissolved film former is flowed from a head box onto a moving heated drum having a highly polished surface. The solvents evaporate off and the film is stripped from the drum as soon as it is dry. A similar application is shown in *Figure 15.* In this case a highly polished endless metal belt replaces the drum.

In *Figure 16,* coating is applied to one side of a web. The coated side is then squeegeed into intimate contact with a highly polished drying drum and dried. On being stripped off the drum, the coating has dried in an exact reproduction of the drum surface and requires no calendering.

Another method of producing a cast coated surface is shown in *Figure 17.* In this case, the web to be coated and a highly polished, waterproof web such as regenerated cellulose or a plastic coated paper or cloth are laminated together between a pair of squeeze rolls, using coating color as the binder. After drying, the waterproof web is stripped off. The coating adheres to the coating web, and again has a highly polished surface that requires no calendering.

Figure 18 shows another variation of the process shown in *Figure 17.*

4. Knife Coaters

In the knife coaters, the coating is either troweled onto the web by means of a suitable knife or scraper, or the coating is applied by other means and subsequently troweled into a uniform film of the desired thickness.

Figures 19, 20 and 21 show three different arrangements of the pure trowel type of knife coaters, widely used for applying very viscous materials, such as rubber compounds, to webs. The color is laid down just ahead of the knife and is pulled into the juncture between the knife edge and the web by the motion of the web itself. The knife has a metering or gate action, permitting a continuous film of color to travel with the web, and the thickness of the film is governed by the setting of the knife.

Figure 22 shows the so called Upside Down Knife Coater, which is widely used for stain types of coating such as Blueprint, and is also used for

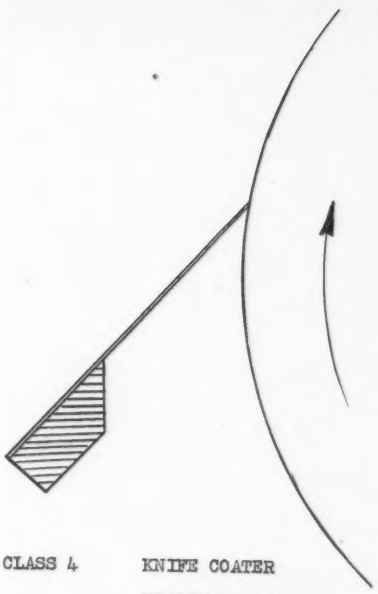


Figure 27

asphalt coating. The color is applied to the web in excess by means of a color roll which, depending upon the type of color used, may travel either with or countercurrent to the travel of the web, the latter giving the greater excess. The excess is then scraped off with the doctor knife and returned to the color pan.

Another adaptation of this principle which is used whenever impregnation of the base sheet is wanted is shown in *Figure 23.* In this case, the knife is positioned at some distance from the color roll. The excess color which is scraped off cascades down the vertical portion of the web and is returned to the color pan.

Figures 24 and 25 show cross sections of representative doctor bar types used for various coatings. *Figure 26* is a longitudinal view of a wire wound doctor known as an "equalizer" rod which is commonly used in coating carbon paper. The amount of coating which passes the rod is governed by the spacing between the high spots of adjacent wires, which in turn is dependent upon the diameter of the winding wire. In use, this type of rod is usually rotated continuously, and countercurrent to the travel of the web.

Figure 27 shows a "Butter Spreader" type of doctor used on some types of pigmented coatings.

The Air Knife Coater, *Figures 28 and 29,* differs from other knife coaters only in that the doctor is a thin blade of high velocity air. The doctor is accordingly both extremely flexible and does not impose any great strains on the sheet. Consequently, the air knife can be used as a slicer to shave off the excess coating on the web rather than as a solid barrier which scrapes off the excess.

As shown in *Figure 28,* the coating is applied in excess to the web with a conventional color roll running partially submerged in a color pan, and the air knife slices off the excess coating and returns it to the pan. Optionally, and more commonly, the sliced off excess is collected in a separate pan and returned to a holding tank, as the air blast stirs a lot of air into the

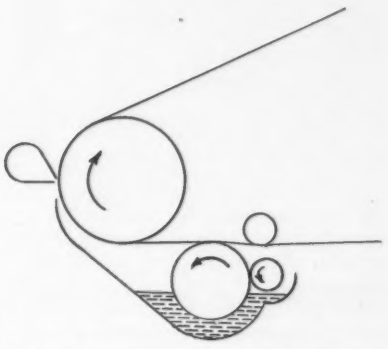


Figure 28

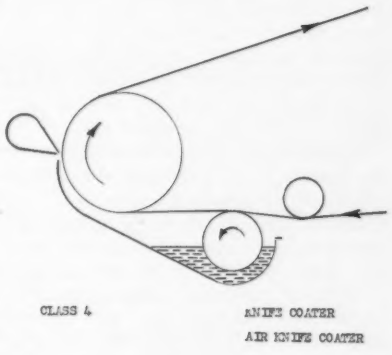


Figure 29

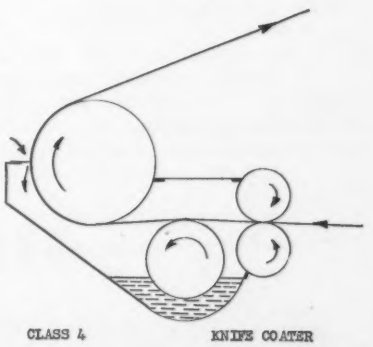
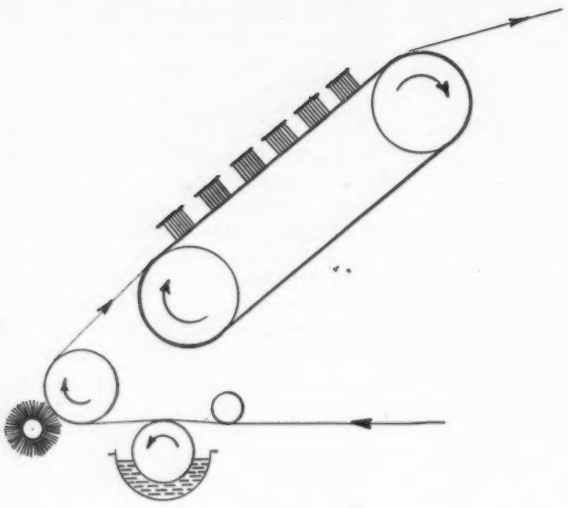
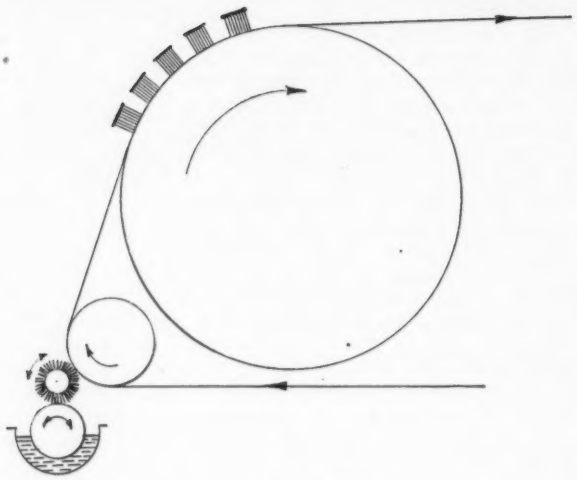


Figure 30



CLASS 5 BRUSH COATER

Figure 31



CLASS 5 BRUSH COATER

Figure 32

returned coating color, which accordingly becomes foamy enough to cause trouble. *Figure 29* shows the same arrangement, but with a metering roll added to the color roll in order to enable the latter to apply a more uniform film of coating to the web. An excess is always applied to the web in this manner, as the air knife does not work properly unless it can slice into the coating and roll up a bead of color at the point of contact. However, the work that the air stream has to perform is materially lessened with this arrangement, which results in smoother coatings with less air, and accordingly less foaming trouble.

Figure 30 shows a different approach to the air knife principle. The sheet enters a combination color pan and vacuum chamber through a pair of seal rolls, the coating is applied, and the sheet emerges from the vacuum chamber through an exit slit having a controlable opening, and the atmospheric air rushing into the vacuum chamber smooths out the coating. This coater has been tried out in various forms by a number of people, but suffers from a number of defects, of which the tendency of the coating color to become deaerated and foam excessively is most troublesome. The mechanical construction and maintenance of a reasonable vacuum has been largely solved and is no problem. However, the air knife in this type of coater will not remove a controlled excess of coating. It can only smooth out a previously applied film or remove substantially all of it, there is no in-between point. Consequently, the simple applicator roll shown in the diagram will not suffice, but the coater works very well with a proper color metering system, particularly if the doctor slot is replaced with a venturi type of throat, in which case very uniform films of coating can be applied.

5. Brush Coaters

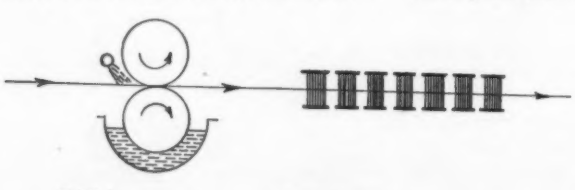
All Brush Coaters work on the principle of applying the desired amount of color to the web, and subsequently smoothing this applied color into a uniform film by means of oscillating brushes.

In *Figure 31,* the color is applied by means of a conventional color roll running partially submerged in a pan of color. The amount of color applied is controlled by regulating the speed of this roll in relation to that of the web. The sheet next passes under a cylinder brush, which exerts a preliminary rough smoothing action on the coating, then to a suction apron which pulls the web through the coating head, and while the sheet is passing over the apron, it passes under a series of rapidly oscillating brushes, graded from coarse bristle in the first brush in the series to a fine, soft badger in the last. These brushes both level out the coating and, to a certain extent, brush it into the surface of the sheet.

Figure 32 shows a similar arrangement, but with a drum replacing the suction apron. In *Figure 33,* the coating is applied to both sides of the web in a squeeze roll arrangement like that shown in *Figure 6,* then under opposed pairs of oscillating brushes which smooth out the coating on both sides of the web simultaneously.

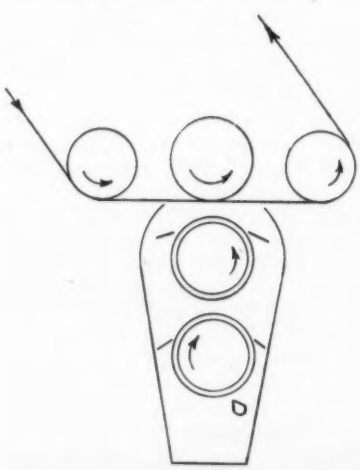
6. Spray Coaters

Over the years, numerous attempts have been made to spray coat color on webs in the same manner in which a



CLASS 5 BRUSH COATER

Figure 33



CLASS 6 SPRAY COATER

Figure 34

painter sprays paint, using atomizing nozzles, but the problems of getting a uniform coating from a number of overlapping nozzles, and of preventing the nozzles from plugging, have never been satisfactorily solved.

In the coater shown in *Figure 34,* the coating color is atomized by centrifugal action. The color is sprayed from a nozzle in the lower end of the coater against a serrated roll, which revolves at high speed and throws the coating centrifugally in all directions, atomizing it in the process. A portion of the atomized color from this lower roll is sprayed against a second roll placed above it, which in turn atomizes it further in precisely the same fashion as the first roll, and flings a portion of this re-atomized color against the web, which travels directly above it. A very even deposit of coating color on the web results. The excess color from the spray rolls runs down the sides and into the bottom of the housing, from which it is returned to the supply tank and reused.

7. Extrusion Coaters

All Extrusion Coaters have the common feature that very heavy, viscous coatings are used, and that these coatings are forced, under pressure from a screw or a ram, through an orifice having the shape and approximate thickness of the desired final film. The action is exactly similar to squezing tooth paste out of a collapsible tube.

Upon leaving the orifice, the resultant film of coating may be deposited directly on the web to be coated, or, in the case of self supporting films, may enter a bath of hardening solution or may be deposited on a non-adhering belt from which it is stripped after drying. In the case of coating a web or depositing the film on a carrier, the web or carrier may travel faster than the film emerging from the orifice, thus pulling it out like taffy to a thinner film than that emerging from the orifice.

To any of you who may be interested in obtaining further and more detailed information on Coating, I recommend investigating the Monograph Series prepared by the Coating Committee of the Technical Association of the Pulp and Paper Industry. The specific volumes of interest are:

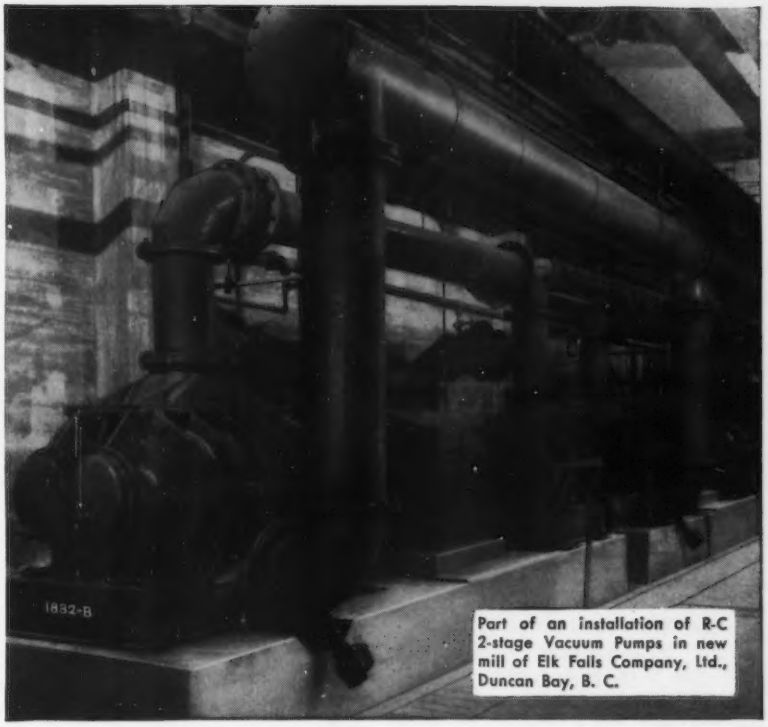
TAPPI Monograph No. 3—Starch for Paper Coating.

TAPPI Monograph No. 5—Resins for the Paper Converter.

TAPPI Monograph No. 7—Pigments for Paper Coating.

TAPPI Monograph No. 8—Machinery for Paper Coating.

TAPPI Monograph No. 9—Protein and Synthetic Adhesives.



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ROOTS-CONNERSVILLE BLOWER

A DIVISION OF DRESSER INDUSTRIES, INC.

Paper Coating

Norman Bearce[1]

Graduate of the University of New Hampshire in Chemistry. Chemist of the Nashua Gummed & Coated Paper Co., 1924-1929. Plant chemist for Lowe Paper Co., Ridgefield, N. J., 1929-1936. Technical director for Champion-International Co., Lawrence, Mass., 1936-1950.

At present, vice-president in Charge of Production at Champion-International.

Has been an active member of TAPPI since 1930, is a former Chairman of the New England Division, and at present is serving on several committees of the National organization of TAPPI.

Introduction

The early production of coated paper was accelerated by the rugged men of early California. To provide recreation and to distribute the gold dug from the earth, they had nearly drained the East of playing cards. Among those who recognized in this situation a business opportunity were a group of men in Nashua, New Hampshire, one of whom believed he could make a machine to coat paper from a continuous web. Gill & Company (1848) was formed, the inventor made good, and paper coated by machine appeared on the market. In 1852, Waldron Company made a coating machine for DeJonge of New York, and from that time coated paper was used for label work and box coverings.

Paper coated top and bottom did not appear until about 1875. A Mr. DeVinne of New York, foremost printer of his time, wanted to make a deluxe catalogue for an important customer, and through various connections the cooperation of Charles Gage was enlisted. Mr. Gage was running a coating mill in Pepperell, Massachusetts, and succeeded in making for Mr. DeVinne the first two-side-coated publications paper. Later, in 1895, Mr. Gage developed a machine that would coat two sides of a web simultaneously and this resulted in considerable expansion of coated paper into the publications field.

From that time to the present the significant developments in the coating art have been: the periodic introduction of many specialties, the replacement of animal glue as a coating adhesive (or binder) by casein and later in part by vegetable starches, the substitution of domestic Georgia clays for English clays, the invention of radically different coating units such as the air-brush and press-roll types, and improvements in drying equipment.

Casein was introduced about 1890 but was not generally accepted as being better than glue until much later. Starch was experimented with early in this century but did not become a big factor in the industry until the last twenty years. Coating machines continued to be large mechanical painters, with brushes, until the air-brush was perfected to run at higher speeds (about 1930), and soon after that a method was worked out for applying the coating paint, with much less thinning water, by high speed, printing press type machines.

This year approximately one million tons of coated paper will be made, divided about as follows: 53 percent for magazines and books, 34 percent for commercial printing, 10 percent for label and wraps, and 3 percent for other converting.

Physical Structure of Coated Paper

Figure 1 is a sketch of a cross section in dimensions accurately proportioned to show the relative size and distribution of the ingredients of a two-side coated paper, 70 lb. per ream of 500 sheets, 25 inches by 38 inches. From top surface to bottom surface the thickness of this 70 lb. sheet is about 0.0036 inches. Note that the bulk of the coating is considerably less than the bulk of the body stock, and also that it takes only a few paper fibers to make up the thickness of the body stock. Also are illustrated the clay particles, both in the coating and as filler throughout the body of the sheet. The filler clay particles are comparatively large and can be seen in their characteristic shape as rather thin, pentagonal plates. The coating clay particles are similar in shape but much smaller. It can also be seen that the adhesive gray shaded areas, completely surround the coating pigments and penetrate down into the body stock from each side. Some of the significant dimensions are as follows: coating clay, in equivalent spherical diameter, will run from less than 1 micron up to 10 microns; the filler clay from 10 microns to 50 microns; fiber thickness will vary from 12 microns to 25 microns; and fiber length from 25 microns to 200 microns. The total thickness of the calendered paper will be 90 microns, of which 75 will be body stock and 15 will be coating.

Classification of Coated Papers

The products of the coating industry may be classified in several ways. *First* from a consideration of the use to which it is put, i.e., magazines and books, commercial printing, labels and wraps, other specialties. A *second* classification could be based on the nature of the coating paint: (a) pigments and film-former carried in water, (b) pigments and film-former carried in organic solvents such as alcohols, naphthas and ethers, (c) emulsions, (d) melted film-formers such as wax and various resins. A *third* basis of grouping would be defined from the method of applying the coating, namely: spray, dip, brush coated, scraper, press roll. *Fourth*, description of the nature of the body stock is also necessary for completely defining the coated paper.

For a complete definition it is well to place a coated paper in all of the above classifications; for example, we would say of a certain paper with a gold-like surface that it is (1) a box wrap, (2) made with an organic solvent formula, (3) applied by a scraper (or doctor) type of coating machine, (4) on a strong kraft base.

Table I includes coated papers classified under the systems outlined above.

The Coating Process

The coating process lends itself readily to a breakdown into four departments: color preparation, application of coating to the body stock, drying (or setting), and finishing.

Color preparation involves processing the various ingredients, blending them and imparting to the final mixture the characteristics demanded by

[1] Vice-President in Charge of Production, Champion-International Co., Lawrence, Mass.

NEW IN STARCH TECHNOLOGY

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(U. S. PATENT NUMBERS 2,516,632; 2,516,633; 2,516,634)

PENFORD GUMS are the products of an exclusive patented process which makes it possible to attach hydroxyethel groups to starch molecules by strong ether linkages. This produces a series of starches which have the desirable characteristics of both synthetic water soluble film forming polymers and corn starch. The introduction of hydroxyethyl groups into the corn starch molecules inhibits any tendency towards reassociation of the starch molecule and resultant gelling or "set back" of the Penford Gum pastes, and at the same time greatly increases the affinity of the polymer chains for water.

PENFORD GUMS produce very stable hydrosols with a cohesive or "long" character, greatly increased clarity, and negligible tendency to gel and retrograde on cooling and ageing. The films formed on drying Penford Gum hydrosols are exceptionally clear, strong, smooth and flexible. Though non-tacky, even at high humidities, they readily redissolve in water.

PENFORD GUMS are produced in a wide range of viscosities, with the more viscous being equivalent in hot paste viscosity to regular unmodified corn starch, while the thinnest is similar in hot paste viscosity to the higher modified conventional thin boiling starches.

PENFORD GUMS gelatinize at lower temperatures than regular corn starch and the granules are rapidly dispersed on cooking to form very homogeneous, viscosity-stable hydrosols.

PENFORD GUMS retain their cohesive and non-gelling character when cooked in either acid or alkaline conditions.

PENFORD GUMS are used by the paper and paper board industry to improve sheet characteristics by application in the beater, size press, calender stack and on the coater.

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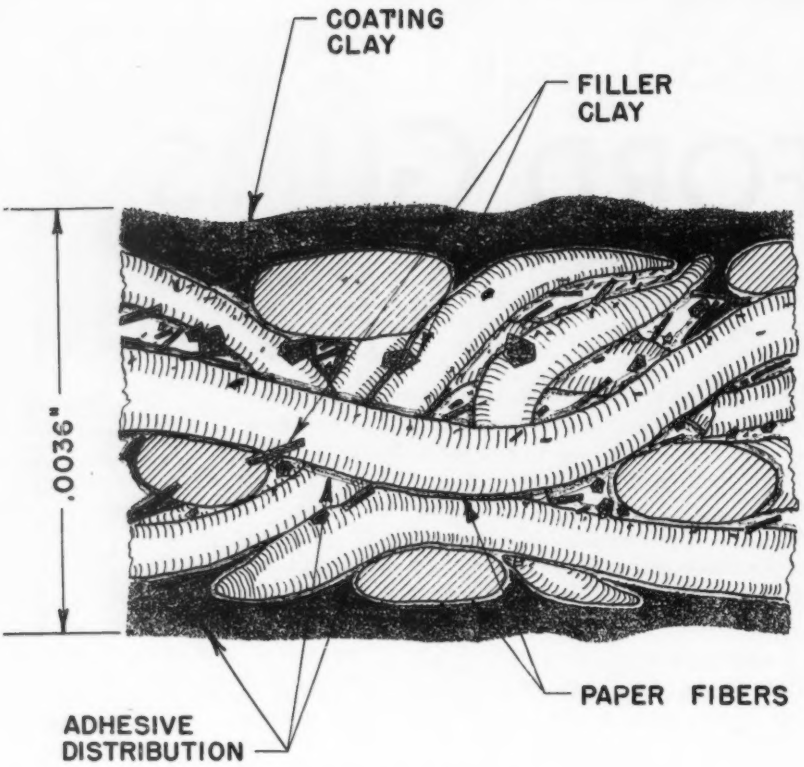

Figure 1—Cross Section Coated Paper

the end-use and by the coating method.

The components can be conveniently grouped as follows: the film-former (adhesive), the pigments or fillers, the solvent, and the modifiers. To illustrate a typical procedure we will select color for publications printing, because this is the big brother of coating, and other coatings are similarly handled. The principal pigment is clay, selected as to particle size, brightness and cleanliness. This is usually received dry, and must be completely dispersed in water by means of various agitators, kneaders or mills. Taking casein as the representative film-former, it must be dissolved in water containing some alkali. The selection of alkali and the cooking procedure is an important control in the formulation of coatings. The casein solution is then blended with the clay slip and, during the mixing period, colors and other modifiers are added.

The modifiers include: oils or fats to control frothing, surface active chemicals to control flow and wetting properties, tanning agents to give the dried coating resistance to wet-rub and waxes to aid in the finishing operation. The coating color is ready for the machine, when it is mechanically worked to the proper texture, diluted to the right percent solids, and approved for color and bonding strength.

Typical coating components are listed in *Table II*.

Coating application is accomplished by machines consisting of: a color intake and reservoir, a metering unit, a transfer unit and distributing units. They may range in width from very narrow to 10 to 12 feet and in capacity up to three to four tons per hour.

The diagram in *Figure 2* illustrates the various possibilities of inter-combining different types of the four functional units:

Following the coating application the coating must be solidified by *drying*, except for hot melt coating or those that are set by special means. The purpose of the dryer is to remove volatile material and leave the paper in suitable condition for calendering or other finishing operations. This is a more critical operation than is generally recognized. It has been said that "paper is made in the beater"; some might as arbitrarily say that coated paper is made in the color-room. Such statements are subject to considerable qualifications, as it can be readily demonstrated that many qualities in the finished paper are so because of their history in the dryer and in the finishing room. To illustrate the significance of dryer control, consider a mineral-coated paper for printing purposes. It can be appreciated that the distribution of the adhesive (or film-former) can determine the performance of the paper; principally how it will finish, how it will receive the ink and how well it will resist picking on the printing press. After the fluid film is applied to the surface of the body stock, the liquid portion (containing the film-former) tends to be absorbed into the paper, as indeed it must be to some extent, to insure the bonding of coating to stock. Beyond that point, however, expensive material is wasted. Opposing this migration are other forces, *one of which* is the rate of drying. It follows then that too rapid or too slow drying can cause unfavorable distribution of film-former, between coating and stock. Also the final stages of drying are carefully controlled as the moisture

TABLE I
Coated Papers

	Coating Type*	Coating Machine**	Body Stock***
Printing papers			
Magazine	W	B,R,M,D	B
Advertising	W	B,R,M,D	B
Label	W	B,R,M,D	B
Box Covers			
Embossed	W,L	B,R,D	C,D
Plates	W,L	B,D	B,C
Friction & flints	W	B,R	B,C
Brush enamel	W	B,R	B,C,F
Metallics & micas	W,L	B,R,D	B,C,D,F
Imitation leather	W,L	B,R,D	D,T
Velour	W,L	M,D	C,D
Waterproof	W,L,E,H	B,R,D,S	C,D,F,T
Greaseproof	W,L,E,H	B,R,D,S	C,D,F,T
Wraps			
Alkali proof	W,L,E,H	B,R,D	C,D,F
Anti-Tarnish	W	B,R	B
Stain proof	W,L,E,H	B,R,D,S	C,D,F,T
Vapor proof waxing	L,E,H	B,R,D,S	D
Board			
Boxboard	W	B,R	F,T
Blanks	W	B,R	F,T
Railroad	W	B,R	F,T
Tag	W	B,R	T
Toughcheck	W	B,R	T
Miscellaneous			
Wall paper	W	B,R,D	(hanging)
Playing card	W,L	B,R,D	T
Abrasives	W	B,R	D,T
Adhesives	W,L,E,H	R,D	C,D
water			
pressure			
heat			
Duplicator	W,L,E,H	B,R,D	B,C,D
decalcomania			
transfer			
carbon			
Safety	W	B,R,D,S	B,C,D

* Coating Types:
W—water paints
L—resin solutions (lacquers)
E—emulsions
H—hot melts

** Coating Machines:
B—brush coater
R—roll coater
M—press roll coater
S—spray
D—scraper

*** Body Stock:
B—book; moderately strong, 50# to 100# basis, usually white.
C—cover; moderately strong, light to medium weight, often colored.
D—strong paper, from very light to heavy basis weight (sulfite, kraft, rag).
F—lined news, 6 point to 30 point.
T—strong homogeneous card board.

Dependable Source for Paper-Making Chemicals

Burke E. Cueny, of Butler Paper Co., inspects paper samples.

How product knowledge can help sales

Paper executive points up value of keeping informed on progress in paper making . . . cites use of Wyandotte Purecal M in finish

"I think the use of PURECAL M in paper finish is one of many developments in our industry which every paper salesman should know," says Burke E. Cueny, vice president and general manager of Butler Paper Company, Detroit. "He can't help but profit from such knowledge.

"In my experience selling letterpress and offset printing and now selling paper, I find that the more information I have on how paper is made and finished the more valuable I am to my employers and customers.

"Purecal is a real quality worker in a paper finish. It insures more whiteness and uniformity, takes ink well, and dries quickly. Customers of mine, using paper finished with Purecal, are never hard to resell on the same sheet."

BULLETIN BOARD

Soda Ash, Caustic:
Supply of these chemicals is currently good; and we are expanding our production facilities, assuring a reliable supply to meet growing demands of the paper industry.

Carbose*:
New Wyandotte Carbose VL is the lowest-viscosity sodium carboxymethylcellulose ever available. It is now being used with outstanding success in calender stock applications. Production of Carbose VL is being expanded to meet increasing demands. Details and samples free.

Kreelon*:
Experience has proved that Kreelon 40, Wyandotte's **high-solubility** alkylarylsulfonate detergent, in proper formulation, can improve the deinking of waste paper 10-20%. Let our representative call on you. Samples available.

To Paper Makers

Wyandotte PURECAL M is a pigment of highest purity for paper coating. It is ultrafine in quality and particle size, free of grit and other abrasives, readily and easily dispersed in water.

These inherent characteristics insure a uniform, smooth coating of high whiteness and good hiding power.

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If you are using PURECAL M in your coated papers, see that your sales force is capitalizing on it. If you are not using Purecal, write for complete data. *Wyandotte Chemicals Corporation, Wyandotte, Michigan. Offices in Principal Cities.*

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CHEMICALS
FOR PAPER MANUFACTURERS

TABLE II

Typical Coating Components

Adhesives	Pigments	Solvents	Modifiers
casein	English clay	water	pine oil
starch	Georgia clay	ammonia	sulfonated oil
latex	calcium carbonate	caustic	formaldehyde
polyvinyl alcohol	satin white	borax	surface active agents
soya protein	titanium oxide	soda ash	wax emulsions
	barium sulfate		preservatives

left in the web determines the plasticity of the paper and consequently its reaction to calendering or other finishing operations.

The older dryers were of the "festoon" type, where the freshly coated paper was picked up by moving rods, hung in long folds and exposed to circulated hot air. These dryers have been replaced by straight-pass, enclosed ovens, or by steam-heated drums about which the paper is successively wrapped as is done on paper machines.

Following the drying, the remaining operations belong to the *finishing* department and include calendering and otherwise modifying the coated surface; sheeting; trimming; slitting; reeling; inspecting and preparing for shipment. All these operations must interest us as each figures, much or little, in the cost of the final shipment.

The super calender is a stack of large heavy rolls, through the nips of which the web of paper is threaded and run at high speeds. Pressure, friction and heat combine to compress the paper and impart a gloss to its surface. A *friction* machine is a special type of calender; *flinting* is an allied operation that gives a very high gloss; *brush finishers* afford a different means for producing high gloss.

A large portion of decorative papers is embossed, i.e., the surface is raised or depressed in prescribed patterns, by press rolls on which the pattern has been etched. The patterns are almost limitless and produce a popular class of specialties.

Rolls of papr are reduced to sheets on *cutters,* consisting of knives mounted on rolls which chop off sheets of predetermined length. For more accurate dimensioning these sheets are trimmed on *guillotine* trimmers which are a sort of chopping block on which a lift of a hundred or more sheets can be trimmed on four sides.

Paper is often shipped in rolls, wrapped and protected against the hazards of transportation. If sheeted it is shipped in cases or skids. In the latter package several reams are piled on a rugged platform, strapped down and wrapped with strong waterproofed paper. When received by the customer the skid is readily unwrapped and is conveniently ready for printing or other use.

Grading and Evaluating Coated Papers

With paper, as with many commodities, it is difficult to appraise relative values. How can a buyer know that a lot of paper, from which he has samples, will be adequate for the use planned for it? How can the supplier of paper be confident that his paper will meet the needs of his customer? Through the efforts of the technicians of the industry, it is now possible to establish acceptable specifications for most types of paper, and both buyer and supplier will worry less if they proceed on this basis.

To evaluate a paper sample requires fitting measurements of its various qualities to established specifications. To establish the specifications requires careful definition of the separate pertinent qualities of paper and determination of the burden put on each quality by the use requirements. To measure these qualities has necessiated the development of reliable instruments of specialized nature. It sounds complicated, and it is, but perhaps it will become clearer from *Table III.*

As seen from *Table III* these qualities can be measured by standard instruments and procedures and, by these, manufacturing operations are controlled and the final product evaluated.

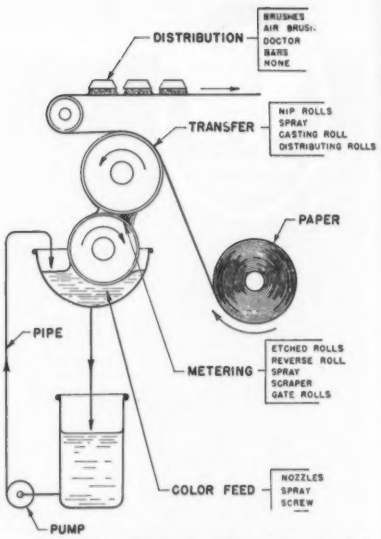

Figure 2—Combinations of Functional Units for Applying Coatings

It is interesting to note that improvement in quality inexorably brings an increase in cost. It seems true that the inexpensive pulps are the weakest, the brightest pigment the costliest, and so on. The following are some of the qualities that must be paid for, and by the same token if you recognize them in paper you are sure that it is a quality grade: high strength, printing smoothness, high brightness in whites, purity of color, high gloss, high specific resistance of any sort.

TABLE III

Quality	Specimen Specifications	Methods of Testing	TAPPI Standards
1) Dimensions:			
Sheet Size	25" x 48"	measuring stick	
Thickness	.0032"	thickness gauge	T 411m
Weight	70 lb. per 500 sheets	basis weight scale	T 410m
2) Strength:			
Tear	44/40	Elmendorf tester	T 414m
Burst	18	Mullen tester	T 403m
Tensile		Tensile tester	T 404m
Stretch		Tensile tester	T 457m
Fold	30/10	Schopper or M.I.T. tester	T 423m
3) Coated Surface:			
Solubility	insol.	wet-rub tester	
Ink Receptivity	0.6	proof press	
Ink Penetration		K&N inks, special	T 462m
Smoothness	500	Beck, Gurley, Williams	T 479m
Color		Colorimeter, standard samples	T 442m
Brightness	76%	G.E. and others	T 452m
Gloss	80	Ingersol & Oxford meters	T 424m
4) Bottom Side:			
Water Absorption ..	1.4 gm.	Cobb test & others	T 441m
Finish	30%	Glossmeter	T 424m
Color		Standard sample	
5) Specific Resistance:			
to Printing Pick ...	#8	Dennison waxes, proofing press	T 459m
to Humidity	1%/.25%	Lab. exposure & measurement	T 447m
to Age		accelerated exposure & loss of Mullen	T 453m
to Temperature		oven test & loss of Mullen	
to Light	10 hrs.	Fadeometer	
to Water		loss of tensile when wet	T 456m
to Vapor Transmission		Carson and others	T 448m

Literature References for the Coating Industry

Books on coating and converting are few and their information is not complete. The Coating Committee of TAPPI has been working to fill this void, and within the next year or two will publish a book covering very fully every phase of the coating and converting industry. The following are available at present:

The Chemistry of Pulp and Paper Making, Seitermeister. John Wiley & Sons.

The Manufacture of Pulp and Paper, Vol. V. McGraw Hill Book Co.

Technical Association Papers 1930-1951, TAPPI.

The Dictionary of Paper, APPA.

Handling and Shipping Practices of the Paper Industry, APPA.

Starch for Paper Coating, TAPPI. Monograph Series No. 3.

Machinery for Paper Coating, TAPPI. Monograph Series No. 8.

Protein & Synthetic Adhesives for Paper Coating, TAPPI. Monograph Series No. 9.

Technical Terms of the Coating Industry

Basis Weight: The weight in pounds of a ream (either 480, 500 or 1000 sheets) of paper cut to a given size.

Body Stock: The base paper or coating raw stock for plain or decorated coated papers.

Book Paper: A general term used to define a class or group of papers having in common physical characteristics that are most suitable for the graphic arts, exclusive of newsprint.

Broke: Paper that has been discarded anywhere in the process of manufacture.

Bulk: The thickness of a pile of a specified number of sheets when under a specified pressure.

Calender: A set or "stack" of horizontal rolls, resting one on the other in a vertical bank. The paper is passed between all or part of these rolls to increase the smoothness and gloss of its surface.

Caliper: The thickness of paper, measured under specified conditions, expressed in thousandths of an inch.

Coating: (1) a term applied to the substance used to cover the surface of paper or board. (2) the operation of applying a substance to the surface of paper or board.

Color: (1) the ordinary concept of optical sensation. (2) a term applied to any and all coating mixtures before their application to the paper; usually called "coating color."

Cross-machine: The direction of paper at right angles to the machine direction.

Embossed: A term applied to paper on which a raised or depressed design is pressed.

Enamel: Coated paper or the coating material on a paper.

Filler: Finely divided relatively insoluble material in the body stock composition, usually clay or whiting.

Free Sheet: Paper free of mechanical wood pulp.

Furnish: The mixture of various materials that are blended in the stock suspension from which paper or board is made.

Glazed: Applied to paper with a high or gloss polish.

Gloss: That property of a surface which causes it to reflect light specularly.

Machine Direction: The direction of paper parallel to its forward movement on the paper machine.

Mullen: An expression used for bursting strength, as measured on the Mullen Tester.

Pick: The quality of paper as it relates to the tendency of coating or fiber to be pulled away from the sheet surface when removed from printing plates.

Point: One-thousandth of an inch, used in expressing the thickness of paper or board.

Ream: A number of sheets of paper commonly 500 but frequently 480 or 1000.

Reel: A shaft on which a roll of paper is wound.

Seconds: Paper which is inferior to the standard quality.

Sheet: (1) used often as a synonym for paper (2) to cut a web into sheets.

Size: (1) the ordinary definition of area (2) materials binding pigments to or on paper, material imparting to paper resistance to penetration of liquids or vapors.

Slitting: Cutting the web of paper of machine width into narrower widths in the machine direction.

Soda: (1) sodium carbonate (2) the class of paper fiber made by cooking wood with caustic soda.

Sorting: The operation of examining sheets of paper, to remove those that are not saleable as perfect paper.

Specialties: Grades of paper made with specific characteristics to adapt them to definite and comparatively restricted uses.

Splice: The union of two webs of paper.

Substance: Same as "basis weight."

Supercalender: A calender with alternate hard (cast iron) rolls and soft (compressed cotton or paper) rolls.

Sulfite: Paper fiber made by cooking wood with sulfurous acid and a basic bisulfite.

Tear: The force required to tear a paper specimen under standardized conditions.

Trimming: To cut rough sheets on two or more sides to insure exactness of size.

Varnish: A solution of a resin, which, after drying, leaves a thin shiny layer of dissolved bodies.

Wax Test: The result of testing for pick with standard adhesive waxes.

Web: The continuous paper fabric before it is sheeted.

Winder: The machine that rewinds a web into a roll.

Discussion Period

Question: Are the standard pick waxes widely used today?

Answer: They are being quite widely used although efforts are being made to develop more reliable methods for determining the resistance of a paper surface to picking on the printing press. In the hands of one who has become experienced in the use of the wax test, reliable results can be obtained, but it is far from being a scientific procedure. The principal difficulty with the wax test is the disturbing effect on the wax-to-paper bond that can result from various coating ingredients. For example, substitution of synthetic rubber latex for part of the coating adhesive will increase the ability of a given Dennison wax to bond to the surface and give a low pick test although the paper would probably print without picking.

Question: In what sort of paper do you use latex?

Answer: Latex should perhaps have been mentioned when we discussed coating formulations but it has been in use for only a limited time and our experience with it is far from complete. The use of it for substitution of part of our present adhesives seems to contribute to printing smoothness and to improve the folding quality of a coated paper.

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Question: Are phosphates used in coating formulas?

Answer: Some of the complex phosphates such as sodium hexametaphosphate and the polyphosphates are very efficient clay de-flocculating agents. In making up clay slips as high as 60 percent solids, the use of such agents is necessary to give fluidity to the slip. They also have value in sequestering interfering metal ions and in otherwise controlling the rheological qualities of the final coating mixture.

Question: How is it possible to make coating smoother with brushes or smoothing rolls.

Answer: It is almost impossible because of surface tension to transfer fluid color from a roll to a moving web, without the formation of ribs of coating. The wet coating does have a levelling tendency but to enable this to be effective, the larger hills and valleys are broken down into smaller ones by means of brushes and smoothing rolls. In the case of high solids transfer, no smoothing devices are used, as the coating sets more readily. Such coatings act as do printing inks on a printing press. The film on the applicator roll comes into contact with the paper in the nip and the transfer is accomplished by a splitting of the film as many necked-out areas of material. These necked-out areas, like an inverted cone on top of an unright one, pull out until the cross-section of the narrowest part is weak enough to break under the forces exerted by the pull of the machine. The area of these many cross-sections is a function of the viscosity of the coating material and the speed of the machine, and it follows that rheological control of the color is the secret of making good coated paper by this process.

Question: What is the function of sizing materials in the coating body stock?

Answer: Sizing is put into the body stock to impart a degree of resistance to water penetration. We might look on sizing as an assist to the rheological properties of the coating. If we retard the adsorption of water from the coating it will remain fluid longer and thus contribute to the final levelness.

Question: Can you tell us something of the economics of coated paper?

Answer: I believe the main reason for their use is not one of economics. It might be expected that coated paper per pound would be cheaper than uncoated paper as, in general, the coating itself is lower in price than the body stock. However, because of inincreased loss of trim, waste due to additional operations, and conversion costs, coated paper is not produced more cheaply. The appeal of coated paper is that it gives superior printing results and printing performance and in addition probably results in an overall saving to the printer.

Question: Does coated paper have a tendency to curl?

Answer: There is a curl problem in connection with papers coated on one side. The coating reacts differently to changes in relative humidity than does the body stock and unless the moisture in the paper is closely in equilibrium with that of its surroundings trouble will result.

Question: Would there be any advantage in experimenting with organic resins and pigments?

Answer: I think the cost would be discouraging. There are some pigmented papers made with synthetic resins but mostly for special end-uses such as grease-proof wraps and vapor-resistant material. For bonding clay and similar hydrophilic pigments, there is a theory that the adhesive used should also contain hydrophilic groups. There is probably a chemical (or hydrogen) bond between the adhesive, the pigment, and the paper fiber. Besides having many OH groups their location is important. For example, polyvinyl alcohol is a much more efficient binder than starch probably because of stearic hindrance. When it is considered that 90 pounds of pigment is often bonded together, and to the body stock, with only 10 pounds of adhesive it can be realized that the film former has to be very efficient. I doubt that hydrophobic resins could accommplish this result.

Question: What types of starches are used?

Answer: Briefly, any starch treated to a suitable viscosity, without conversion to excessive amounts of sugars, is worth consideration as a coating adhesive. Converted starches can be purchased as oxidized, chlorinated or dextrinized. Raw starches can be enzyme converted in the coating mill. Corn starch is the most popular at present but tapioca and potato starch have also been widely used.

Question: What are some of the viscosimeters that are used for control and research?

Answer: With the so-called medium solids coatings such as are used on brush coaters or reverse roll coaters the common laboratory viscosimeters are applicable, such as the MacMichael, Störmer, or Brookfield. For high solids operations, work is still in progress to develop a completely satisfactory instrument for measuring high shear viscosity in all its complications of thixotropy, dilatency, yield values and levelling index. The best one at present is the so-called Hercules Hi-Shear viscosimeter.

Paper Testing and Specifications

Joseph King[1]

Over thirty years experience in paper making and paper testing.

In any discussion of Testing and Specifications as related to the manufacture of sulphite papers it is necessary to consider some of the factors that enter into the manufacturer's efforts to produce a uniform product.

Briefly these are as follows, as related to the basic pulp:

A. Wood Suppy

1. The trees selected and the percentage of each type cut.
2. Method of delivery to the mill, or length of time in the water before yarding, and method of cleaning.
3. Length of storage and conditions of storage in the yards.

B. Pulp Mill

Method of chipping, moisture content of the chips, green or seasoned wood, cooking method, bleaching method used, and degree of washing.

These factors have a bearing on the degree of variation in the pulp batches and the paper-maker's problems are governed by these variations. The pulp mill generally reduces this factor by blending the various batches to produce a uniform pulp; nevertheless, a certain amount of variation is bound to exist.

Mills that make their own pulp have tests made on pulp batches for control purposes. These tests are directly related to the paper being made. The usual tests employed are as follows:

Alpha-cellulose content
Copper number
Viscosity
Acidity (or pH)
Fiber length
Initial Strength
Beater Value
Brightness

These tests are given to the paper mill and are a guide to the handling of the pulp in the beaters.

In the paper mill continuous tests are made as follows:

Beater Room

1. Moisture content of pulps used—to insure proper density.
2. Freeness tests—to insure proper stock preparation.
3. pH examination—for proper sizing balance and acidity.
4. Check on color used—to insure uniform shades.
5. Density of stock in chests.

Machine Room

On the paper machines, tests and adjustments are being constantly made to insure the final product will be uniform and made to meet certain standards.

The men responsible for these machines and the paper produced are highly skilled and have learned to know all the adjustments necessary to produce the variety of papers being manufactured. They must control the weight, moisture content, uniformity across the sheet, formation, finish and clarity of watermark. They are also responsible for the strength of the sheet being produced.

The strength and other tests are taken by paper testers, trained men who take the various tests and report them to the paper maker as soon as they are made, to enable him to make his adjustment.

Important tests taken at this point cover the following qualities:

1. Basis weight and caliper
2. Moisture content
3. Sizing
4. Mullen (Burst)
5: Tear
6. Curl
7. Smoothness

In addition it may be necessary to have folding endurance, densometer tests, brightness tests, and opacity or transparency tests taken at the machines if said qualities are included in the specifications.

At this point it might be well to describe the tests used to measure these paper characteristics and to comment on their value.

Basis Weight. The test consists of cutting a sheet to a standard size and weighing on accurate scales that are calibrated directly in pounds for 500 sheets, (480 sheets may be called for). Trade custom allows a tolerance of ± 5 per cent and if the paper is beyond this range it must be remade.

Caliper. This test consists of placing the sheet in a thickness gauge and taking readings on the gauge, usually in thousands of an inch. Variations of ± 5 ten thousands of an inch from standard are usually allowed on this specification.

Moisture Content. This test is made by weighing a sample sheet, placing it in a hot oven until dried, then weighing and figuring the amount of moisture removed. This test is important because moisture content affects the basis weight and other qualities of the paper being produced.

Sizing Test. In order to determine the effects of the beater and surface sizing used it is necessary to measure the sheet for this quality. One of several methods used is to float pieces of the paper on a standard ink solution that is kept at a given temperature. The time required for the ink to "strike through" the sheet is a measure of the water resistance of the paper. Specifications on this test are based on the grade being made; penetration time must be kept above certain minimum values.

Bursting Strength. This is a measure of the resistance to bursting strain.

The test consists of forcing a rubber diaphgram against the clamped sheet and measuring, in pounds per square inch on a gauge, the force necessary to burst the sheet.

Specifications usually call for a minimum bursting strength, but certain types of paper may have a maximum bursting standard where softness rather than hardness of the sheet is necessary.

[1] Supervisor of Paper Testing, Eastern Corp.

Tearing Strength. This is a measure of the resistance to tearing strains of the sheet being produced. This test consists of clamping a standard number of sheets of a standard width in the tester so that part of the paper is held in the movable sector and the remainder is held in the stationary clamp. An initial cut is given the sample and the sector released. The resistance to tearing is indicated on a scale over which a pointer moves and indicates, in grams, this resistance.

The value of this test is much discussed but when used with the bursting strength it is a good control combination on the paper machines.

Test for Curl. Several methods have been devised to measure curl but the simplest method seems to be to measure the rigidity, that is, note the difference in drop of the sheet edge between the wire and felt sides, measuring the sheet in both the machine direction and cross direction will indicate whether the sheet has a tendency to curl.

A question frequently asked about curl is how it can be controlled. The answer is that there are many factors that affect curl, and some of them can be listed as follows:

1. Type of pulp used.
2. Degree of beating.
3. Jordan settings.
4. Uniformity of fiber length on the wire.
5. Amount of water on the wire.
6. Felting and press treatment.
7. Dryer temperature.
8. Tub sizing—method of application.
9. Calendering.
10. Moisture of sheet on the reel.

This lists only a few of the possible conditions that may enter into the curl problem. Often the paper maker will change only one or two of these and correct curl. Basically, it is probably safe to say that a majority of curl problems can be corrected at the paper machine by changing drying conditions.

Densometer Tests are made by measuring the time to force a given volume of air through the sheet.

Specifications for this test may require times from several seconds to many minutes. according to the type of sheet being produced.

Brightness Tests are taken on a photo-electric measuring device made by the General Electric Company or an instrument that has been calibrated to this machine.

Opacity Tests are made on papers having this specification, which are papers requiring either maximum opacity or a sheet requiring transparency. Printing papers must be opaque. Tracing papers must be transparent. The test is a measure of the contrast ratio between light reflection from black and white surfaces back of a sheet of paper and is measured on a photo-electric instrument.

Smoothness Tests are made on an instrument into which a piece of paper is clamped in such a way that when air under pressure is released or a vacuum set up, the moving air must travel over the paper surface and the time in seconds is measured for a given volume of air to pass. This test is important in certain types of printing papers; it is especially important in the production of office duplicating papers.

Folding Endurance. This test gives an indication of the papers resistance to creasing and folding. The test procedure consists of subjecting a standard width strip of paper being tested to sharp bending and folding under a standard tension, until the strip breaks. The number of folds necessary to cause this break are registered as folding endurance. Tests are made on strips representing both the machine direction and the cross direction. Both the Schopper and M. I. T. machines are acceptable to the trade and specifications are put out for both.

This test is generally called for in certain bonds, ledgers and high wet-strength papers.

A study of this test shows a wide variation in results, between strips and between machines; there is no direct comparison between the M. I. T. and Schopper testers.

In making all these tests at the paper machine it must be realized that the moisture content of the paper being tested is of great importance as many of these tests are sensitive to moisture changes. Therefore allowance must be made for moisture variations in evaluating results.

Laboratory Testing

As mentioned, testing at the paper machines must be done as rapidly as possible to be of any value to the paper maker, but when comparison is to be made with consumer specifications, these tests must be made under controlled conditions. This means that the paper must be conditioned for at least two hours in a humidity room kept constant at 50 per cent relative humidity and 72 degrees Fahrenheit. This permits accurate testing and the obtaining of results comparable with consumer specifications.

Tests made under these controlled conditions are:

Basis weight
Caliper
Bursting Strength
Tearing Strength
Folding Endurance
Air Resistance (Densometer test)
Smoothness tests
Tensile Tests

The tensile test was not listed among machine room tests as other tests applied usually indicate that this specification will be met. This test measures the load in pounds required to pull apart a strip of paper of definite width. Two machines commonly used are the Scott and the Schopper tensile testers.

This test is important on papers that are subjected to strain such as would be applied in web presses, papers converted to soda straws, or teletype paper.s.

Aside from the tests listed there are many other tests that may be necessary to meet specifications on various papers as follows:

Fiber Analysis. To make certain the right pulps have been used in the proper amounts. This test is done with selective stains under the microscope.

Ash Content. This test is made by ashing a weighted portion of the paper in a hot muffle and determining the percentage remaining. This gives an indication of the amount of loading used and assures that this amount is not above specification allowance.

Acidity of most papers is of importance in papers intended for permanent records. This test consists of extracting a weighed volume of paper in hot or cold water and determining the hydrogen ion concentration of this extract by use of a pH meter. Material with pH values not less than 4.8 are considered safe for this type of paper.

Rosin Content. Because long exposure to light of papers having excessive rosin sizing results in a general discoloration, the amount of rosin sizing should be kept to a minimum. To test for rosin content the hot extraction method using rosin solvents is used. After extraction and removal of the solvent the residue is weighed and the percentage figured. This percentage should be less than two per cent for most papers.

Ink Receptivity of Printability. To measure this quality of a paper the oil penetration test is used. This consists of placing a drop of standard castor oil on the sheet surface and measuring the time for penetration. This test is important in the production of mimeograph, book, and some offset papers.

Surface Strength. Resistance to picking is a factor in producing papers for the present day with high speed presses. Considering that the paper is subjected to a pressure of 40 pounds per square inch, in some cases much more, the paper surface must resist this pressure without breaking down.

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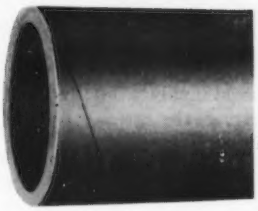

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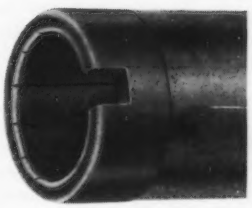

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used for testing the paper. These consist of a series of calibrated waxes that increase in tackiness. These are usually numbered from 1 to 20. The waxes are melted over a flame and applied to the paper surface and allowed to dry. After cooling the waxes are pulled from the sheet and the number noted for that wax which causes the surface rupture.

For good performance, papers should test between 8 and 12, although there have been cases where papers testing below 8 have given good results. In general this test is not consistent with press performance, indicating there are other factors that should be considered in evaluating this test, among which are smoothness and density of the sheet, pressure on the press, and the time factor.

There are many other tests that may be applied in the laboratory, but space would not permit description and evaluation of all of them.

In order that physical and other tests may be accurate it is necessary that all equipment and methods be standardized at regular intervals. For instance equipment must be available to calibrate Mullen gauges and machines, for calibration of tearing testers and folding machines. Constant check must be kept on brightness testers, opacity testers, and pH meters.

The laboratory is also responsible for furnishing standard samples for finish, color and formation, to be used by the paper maker in standard runs. Samples of each run, together with all tests taken on these runs are kept on file for future reference, and for the purpose of changing mill specifications if necessary.

One of the important duties of this department comes when mill difficulties arise that require technical investigations. These problems may require the gathering of data based on tests and analysis or they may be solved by referring to reports on the same problem in the past.

Whenever difficulty develops at consumer points such as print shops, binderies, or converter plants, it may be necessary for a technical man to visit the plant concerned and make a study of the application of the paper in question. This may result in a change of some characteristic of the paper to fit the customer's need.

It is evident that the technical man should have a knowledge of the end use of the paper in many cases.

Micro Analysis

A valuable instrument available to the paper tester is the microscope. Besides its use for fiber analysis, which is made possible by using stains developed for the process, and permits the analyst to determine the type and percentage of fiber used in a paper, it is also used to determine the treatment given and measure the fiber length.

The miscroscopist is also able to analyze dirt specks and determine their sources. Paper fillers as well as titanium or other opacifying agents used may also be easily identified.

In the study of stock preparation and the effect of treatment in Hydrapulpers, Beaters, Jordans, and Refiners, the microscope in conjunction with a camera can produce photo-micrographs that will show what the different treatments do to the fiber; such pictures are valuable when included in reports of this nature. The microscope is valuable in the identification of the synthetic fibers and resins being used in certain types of papers.

Development of new grades means that the laboratory must analyze and test samples representing the grades under study and determine if any present mill grade can be used. Often a slight change in the furnish or characteristic of a presently made sheet will produce the desired results.

Tests and studies may be called for to make mill operations more efficient, such as beater sizing, dyestuff use, and paper making operations.

Paper mill laboratories may also include office duplicating machines and small offset presses to test for machine operation and printing quality.

Specifications As Related to Consumer Needs

Many times a customer will submit to the mill a long list of specifications of his requirements. Generally these are based on experience in their use and a careful analysis by the mill may indicate that these specifications can be easily met by one of the standard mill brands or slight changes can be made to equal the grade the customer desires. However, it may be necessary to set up an entirely new grade. This could call for different pulps or some chemical treatment to meet submitted specifications.

There are cases where a careful study of submitted specifications will show a combination that is impossible to meet. In such cases a conference must be held with the customer and have modifications made. Usually these changes will result in a sheet that will be entirely satisfactory in all respects.

To illustrate this condition, specifications have been submitted where caliper, finish, basis weight and moisture content are listed in such a way that if three of these tests are right the fourth will not meet specifications. One of these qualities must be sacrificed in order that the others be in balance.

Although this discussion has been chiefly on the physical characteristics of papers, a high percentage of sulphite papers are sold to consumers who depend on the manufacturer to supply papers with the proper strength and other qualities.

Many of these papers are sold on the basis of their *"eye appeal"* alone. That is, they must be bright and free from specks. If the paper has good qualities in this respect the purchasing agent may be interested, but if the sheet is dull looking, specky, and generally unattractive, the sale may be lost even if the sheet is extra strong.

Printing papers must give good printing results; the other general requirements are good printing surface, freedom from curl, and square trim.

Paper for Office Duplicating Machines

Mimeo Papers must have fast absorption to oil base inks and yet resist "strike through," besides being bright and having good opacity. With the introduction of fast drying inks to this process it is possible to use a wider variety of papers with good results.

Spirit Duplicator papers must have a smooth even surface, good opacity, and high brightness. They must be made in a special shade to show good visibility of the purple color used in producing copies.

The Offset Duplicator requires no special papers as these machines will handle any paper from Substance 10 to Index stock with good results; however, the paper for these machines must be cut accurately and lie flat to assure good results.

Papeteries. As most of these papers are run offset in the production of greeting cards or stationery, it is important they have a good printing surface and good creasing or folding quality. Physical tests are of minor importance because of the paper's use.

There are many tests available to the technical man in the paper industry, many of which have been approved by TAPPI. Others not officially approved are of practical value but it is good practice to keep machine specifications at an absolute minimum to avoid confusion and yet secure desired results.

New tests and equipment are being introduced at a rapid rate. These include electronic devices, photo cells, and even devices employing radioactive fission products.

New equipment in automatic control is also being used from the digesters to the paper mill finishing department; in spite of these it will be necessary to have men continually testing and checking paper. Their importance will increase as new processes and equipment come into use.

Paper Testing and Specifications

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Introduction

To develop a background for our consideration of the subject of paper testing and specifications, let us take a look at the reasons for the existence of the topic.

I assume that you are preparing yourselves for careers in pulp and paper. No doubt you are thoroughly aware both of the national stature of this industry (it is generally rated sixth largest in the country) and of the important place it occupies in our country's economy. Whether one examines the available statistics in terms of our gross production (over 26,000,000 tons in 1951) or per capita consumption (nearly 400 pounds) the picture is dramatic compared to that of other countries or to that of the whole world.

You undoubtedly see from time to time, the story of what we are doing in the pulp and paper industry in terms of production, consumption, imports, exports, and so forth, that appear in the various trade magazines.

At this point it may be well to pause and reflect on the mechanism by which this vast commerce in our pulp and paper products is accomplished. It is not just a case of a seller of paper and a buyer of paper contacting each other and agreeing on the details of price and quantity in order to consummate a transaction. No, indeed. Because of the host of different types and kinds of paper made today and the variation in quality within each classification, it is necessary to utilize a common language which defines and describes the paper to buyer and seller alike in terms which they both understand. This is done through paper testing.

The buyer attempts to describe his needs in terms of specifications. These are his means of describing the hypothetical paper he is seeking. For this purpose he does not merely use a set of adjectives to create a mental picture but names the tests to be used and the results to be obtained with those tests. Insofar as possible, he uses for this purpose testing methods and equipment which have been accepted as standard, (that is, suitable for reference purposes) by such organizations as TAPPI, ASTM, and the like. The seller uses the same language and the same "yardsticks" to describe what he has to offer.

The economic cycles of the paper and paperboard industry are, in general, less violent and less frequent in their swings than those of some of our other leading industries. Nevertheless, they do exist, a fact of which you will become more aware after you are out in the industry. It is inevitable, and normal, that there are times when we have a seller's market and there are times when we have a buyer's market. Much of the time we have both at once, a buyer's market in one part of the industry and a seller's market in another part. Therefore, it is necessary at all times to have a common denominator, the common language of paper testing, which will enable the buyer and the seller to understand and to agree as to what is wanted and what is offered. In a buyer's market the emphasis is inclined toward the buyer's specifications and the seller takes the necessary steps to meet them, insofar as possible. On the other hand, in a seller's market, the seller is a little bit more independent and the buyer's specifications are a little more subject to modification to meet those of the seller. However, by and large, the old law of supply and demand influences price more than it influences quality and the specifications tend to remain reasonably stable on a long term basis. The position of the industry on the economic cycle influences the tolerances allowed on the specifications rather than changing the specifications themselves or the methods used to express them. The point I want to make is that the job of adequately defining the quality of paper is quite independent of the economic cycles. As technical men, concerned with the problem of defining paper quality through the medium of paper tests, we can be glad that this is the case. The strictly factual assignment of evaluating paper quality is one which not only deserves, but requires the best efforts of the combined technical talent in the industry.

So much for a bird's eye view of the function performed by paper testing and specifications in the general case of direct participation in the buying and selling of certain types of paper. There are, of course, many other indirect functions of testing and specifications which serve to accomplish the same purpose. For example, in the types of paper product which the housewife selects from the shelf at the corner store, the consumer's specifications are not made known directly to the seller in terms of tests and test values and tolerances. However, the consumer's use requirements lead to acceptance or rejection on the basis of certain characteristics which the seller can reduce to numbers through a process of evolution and elimination. The seller can then use these tests and these numbers to specify to his manufacturing department what is needed to assure customer acceptance. Thus, the customer or buyer is actually setting the quality requirements for the product and establishing the specifications by indirect means. This is just as true as if his participation in this function were more direct.

The usefulness of paper testing does not stop here. No manufacturer can produce a product which will meet specifications without some measure of technical control in his operation. Only

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by following the trends in the effect of process variables on product quality is it possible to keep the product quality within the proper limits.

Scope of Testing

At this point I should like to enlarge the scope of this discussion to include at least a sketchy view of the testing activities in the whole pulping and paper making process because all of it is so inter-related and so necessary to the support and success of our subject "Paper Testing and Specifications."

Two areas of testing are needed for adequate support of a paper making operation. One of these is the technical control of the process, which I have just mentioned briefly. The other is the testing of the raw materials which go into the process. Now, if we recognize that our principal raw material is pulp and that pulp quality has an important effect on paper quality, we can readily see the justification for including pulp testing in this consideration of paper testing.

An interesting analogy can be drawn to illustrate the functional similarity and relationships between pulping and paper making. In talking about our industry and its processes, I would like to put them up against a set of crude equations such as these:

Raw Material + Process = Product

Wood + Pulping (and bleaching) = Pulp

Pulp + Stock Preparation and Paper making = Paper

Thus, in these oversimplified equations we have the skeleton or framework on which we can build the structure of testing, covering all phases.

We have illustrated the scope of this discussion and we have touched lightly on the importance of testing at every stage of the operation, from the buying of paper back through the selling of paper, the manufacturing of paper, the buying, selling, and manufacturing of pulp back to the raw materials for pulp making. Now let us reverse the process and consider briefly the tests which are used in each phase of the operation from start to finish. This discussion will not be complete or exhaustive, but rather merely illustrative.

Testing of Raw Materials

To limit to a reasonable degree the discussion of the testing of the raw materials for pulping, I will pass over the whole field of non-fibrous raw materials lightly. Each of these items, such as water (which is so essential to the process), fuels (such as coal, oil, or gas), primary chemicals (such as sulfur, lime, caustic, salt cake, chlorine, etc.), and the many secondary chemicals, has its own specifications and tests which are of great utility and value to us. Likewise I am going to jump over the fibrous raw materials other than wood, such as cotton, rags, straws, waste paper, and the like, in a similar manner.

Even after we have made these sweeping simplifications and narrowed the field to a consideration only of wood, we have plenty of testing problems to be met. The cost of wood is frequently one of the largest single cost items in the production of paper. Therefore, it is important to have both quantity and quality specified and subject to measurement and definition by means of tests. Yet, although we sell most of our paper on a weight basis, we buy most of our wood on a volume basis. There are many units of volume used in this country today, as you know. I will not dwell on the various cubic specifications such as the cord, the unit, the board foot scale, etc., or on the variations and modifications found in each. Suffice it to say that the methods used to define the quantities of wood purchased for pulp making leave much to be desired in terms of standardization and uniformity. The important factors derived are cords per ton of pulp, board feet per ton, units per ton, etc. These are merely crude relationships between wood purchased and pulp made. The equation lacks what the mathematician calls dimensional similarity.

A more direct approach to a material balance across a pulp mill demands a knowledge of the weight of dry wood substance coming into the mill. To derive such information on a cord of peeled wood, for example, we need to establish the wet weight of the cord, test and correct for moisture to get the dry weight per cord or else determine the volume of solid wood per cord, then test the dry density per unit solid volume and calculated the weight. The practical difficulties involved are serious and account for the persistence of the current methods. The statistical problems of sampling wood for moisture and density could well be the subject of an entire discussion period such as this.

Perhaps we should give at least the following very minimum comment to this subject. The job of testing our principal raw material, wood, (which is often one of our most significant cost items) for quantity and quality is one which must not be overlooked, nor should it be underestimated by the technical men in our industry. There is no direct, easy test for wood quality from a pulping standpoint. We can test for growth rate, age, density, moisture, decay and deterioration, extractives, and chemical composition, but it is virtually impossible to predict pulping behavior from these tests from a practical standpoint.

Now we are going to skip over the testing of the many other raw materials used in connection with pulp making. We are going to skip the testing associated with our supporting processes such as water treatment, power generation, ets. Also, we are going to skip the testing of our by-products and waste products in one grand stride. However, we should pause for a glance at the testing concerned with the pulp making operation.

Did you ever stop to think what it would mean if we had to make pulp without the use of any control tests whatsoever? It would be an almost impossible task, involving at best an almost complete sacrifice of our normal degree of uniformity and level of quality. We are so accustomed to and dependent on these tests that we are inclined to take them for granted.

We use tests to control the making of our cooking liquors. If we cannot achieve the desired uniformity in these liquors, we use the results of these tests to compensate in the cooking operations for these variations in the liquors. The cooking schedule itself is controlled by tests, manual or instrumental, in order to follow temperature and pressure cycles and other variables of cooking. We test the pulp for degree of cooking, bleach requirements, and for other pertinent characteristics. In bleaching, again, we test the bleaching and extracting liquors, control the processing conditions, and test results of the process. Some of the modern complex multistage bleaching operations depend heavily on process testing in the various stages for their success.

Pulp Testing

This brings us to the matter of pulp testing. I want to pause here for a little in our rapid scanning of the panorama of the role of testing in our industry for two reasons. First, because this is an area which needs and merits the special attention of our technical forces and second, because it is one of particular personal interest to me. For some years my work has been closely associated with this subject. Also, for about a decade I have had the opportunity of serving as the Chairman of the Pulp Testing Committee of TAPPI, a responsibility which I am terminating next month. While I cannot hope to do justice to this subject in the time available, I will attempt to express some of my thoughts on it.

Let me say at the outset that in its present state of development, pulp testing leaves much to be desired. Viewed through the eyes of a perfectionist, it is very crude. I hope and believe that the next decade will see many times the development and improvement realized in the last ten years. There is much more interest and activity in this field now than there has been at any previous period in history. This should bring accelerated progress. As it is the future with which you will be concerned, I hope that these comments on the present state of affairs may be of interest and assistance to you by way of background.

Perhaps the first problem encountered, which is common to all pulp tests, is that of sampling. It is one which too often is taken for granted. Whether we are performing a physical, a chemical, or a physico-chemical test, in almost every case we are faced with the basic job of securing a small sample which is representative of a much larger lot. This is necessary in order that the test made on the sample will be significant as a measure of the property in question for the whole lot.

As you know, pulp is composed of a large number of discrete fibers of varying size, shape, chemical composition and activity. It is my recollection that in a single gram of chemical pulp there may be from 2 million to 8 million fibers. Taking an arbitrary figure of 10 million fibers per gram, you may be surprised if you calculate the number of fibers in a bale, in a ton, in a railroad car, or in a boatload parcel of pulp. Likewise, in a 500 ton pulp mill the number of fibers represented by a shift, or a daily, or weekly composite sample is staggering.

To get back to direct control problems, one of the most common is, say, a permanganate number test of each digester of pulp. TAPPI Method 214 calls for a 1.0± 2.02 gram sample. On a 20 ton digester, a one gram sample means that roughly one part in 18 million is taken for the test. We know that there is some variation in degree of cooking in various parts of the digester. Also, there is some variation from chip to chip. You can readily see that the one gram in 18 million which is chosen for the test may or may not be entirely representative of the whole batch.

May I emphasize the point, which applies to all testing in the pulp and paper field, that a test result is no better than the sample taken, no matter how accurately the sample size is chosen or determined, no matter how accurate and reproducible the test method used, and no matter how capably and carefully the operator runs the test.

The application of statistical studies to the sampling problem is helping to improve our understanding of the degree to which a given sample is representative of the particular lot. Likewise a study of the normal variability of a given test method in the hands of an average operator is increasing our ability to assign the proper significance to a given test result. Too often an operator is criticized or a test method is condemned when the fault really lies in the sampling procedure. Please do not overlook this matter when you come face to face with testing problems.

The next general weakness in the field of pulp testing is in the interpretation of the results of the tests. Many of our pulp testing methods are indirect and highly empirical. Some of them were developed for a specific use on a certain type of pulp. It is only natural that we should use them as widely as possible. However, too wide application of some methods has led to false conclusions and to a condemnation of tests. It is not infrequent to hear a test condemned because it fails to measure something which actually it cannot and was never meant to measure. It behooves us then to be very critical in our judgment of such tests. We should always ask ourselves two questions: "What is this test supposed to measure?" and "How well does it measure the thing it is supposed to measure?" before we pass judgment.

Just one more general comment about pulp testing, about the methods available: As mentioned above, many of the methods are indirect and empirical. They leave much to be desired. By and large, organizations such as TAPPI, which attempt to provide standard methods suitable for referee testing purposes, are well aware of the limitations and imperfections of the methods. They welcome constructive criticism and continually revise methods when improvements are devised. It should also be remembered that these standard methods are designed for referee purposes, not necessarily for routine mill control. It is very common to use modifications of these methods for control purposes. This has led to some confusion and lack of agreement between parties comparing results. This can be avoided if care is taken not to refer to a method by its TAPPI Standard designation unless the Standard Method has been followed to the letter. If modifications or short cuts are used, this fact should be noted as a part of the result reported.

While speaking of TAPPI testing methods, it may not be amiss to point out that all methods in the book of TAPPI Standards are not Official Methods. Some are suggested methods and some are tentative standards. These have less stature than Official Standards and are usually the newer methods which are in a state of development. Also, TAPPI now has a whole section of routine control tests.

There are several ways of classifying pulp testing methods. One way is to divide them into chemical, physical, and physico-chemical methods. Any such classification is necessarily somewhat arbitrary and you may or may not agree entirely with the following classification.

TAPPI Chemical Test Methods (Pulp)

The TAPPI pulp testing methods usually regarded as *chemical* are the following:

- Cellulose in pulp
- Alpha cellulose in pulp
- Water solubility of pulp
- Moisture in pulp by toluene method
- Methoxyl groups in pulp
- Ash in pulp
- One per cent caustic soda solubility of pulp
- Copper number of pulp
- Permanganate number of pulp
- Chlorine consumption of pulp
- Bleach requirement of pulp
- Lignin in wood pulp
- Pentosans in pulp
- Water soluble sulfates and chlorides in pulp

TAPPI Physical Test Methods (Pulp)

The *physical* methods would include:

- Weighing, sampling and testing wood pulp for moisture
- Freeness of pulp
- Drainage time and drainage factor of pulp
- Laboratory processing of pulp (Beater Method)
- Laboratory processing of pulp (Ball Mill Method)
- Laboratory processing of pulp (Kollergang Method)
- Forming handsheets for physical tests of pulp
- Physical testing of pulp handsheets
- Dirt in pulp
- Forming handsheets for optical tests for pulp
- Brightness of pulp
- Special reflectivity and color of pulp

TAPPI Physico-Chemical Test Methods (Pulp)

Some of the *physico-chemical* methods are:

Cuprammonium disperse viscosity of pulp
Cupriethylenediamine disperse viscosity of pulp
Pitch in wood pulp
Spectral reflectivity and color of pulp.

There are, of course, a host of other test methods used for control and evaluation purposes on specific pulps. In addition, research in the pulp field requires many other tests and techniques, some of them highly specialized such as optical and electron microscope, X-ray diffraction analyses, and the like. I have not mentioned bacterial analyses or many other specialized testing procedures.

Pulp Quality Factors

For paper making purposes, we are principally interested in three quality factors, 1. *Condition,* 2. *Response,* and 3. *Potential,* by which we mean:

1. *Condition* is characterization of the pulp as delivered to the paper mill in terms of fiber characteristics such as source, species, pulping process used, dimensions, color, cleanliness, general strength level, and the like.

2. *Potential* is sheet forming or felting characteristics and sheet strength factors obtainable after refining.

3. *Response* is an evaluation of the rate and type of response to mechanical refining in terms of freeness or drainage characteristics, surface area, surface activity, and fiber dimensions.

The most common, simple approach to the problem today is to test a pulp in a laboratory beater which is maintained as well as possible in a calibrated, reproducible condition, checking the changes in fiber length and freeness as the treatment progresses and testing the handsheets, which are made periodically, for specific volume or density, for strength properties (usually tensile or bursting strength and tearing strength) and for optical or other properties of specific interest. From such data it is possible to define the strength level at a given degree of treatment and to establish the rate of response to this fairly reproducible treatment.

As mentioned earlier, the interpretation of pulp testing data is the weak link in the chain of pulp testing activities. An increasing amount of emphasis is being placed on the "response factor" of pulps and also on the interrelationship between the architectural or structural characteristics of a sheet and the strength properties. Many sheet strength properties in many types of paper depend as much or more on fiber bonding than on individual fiber strength and size. Fiber bonding is very difficult to measure simply and accurately. The aggregate strength of the fiber bonds in a sheet of paper depends on the bonded area and the strength of the individual bonds. The bonded area depends on the distribution of the sizes and shapes and the flexibility of the fibers and on the compressibility of the individual fibers. The bonded area also depends on the orientation and distribution of fibers in the sheet and the way in which they are felted and compacted on the forming and in the wet pressing section of the paper machine. It should be mentioned in passing that drying, calendering, finishing, and converting operations can have a subtractive effect on fiber bonding.

In a paper given before the Fundamental Research Committees of CPPA and TAPPI in Quebec in May, 1950, I discussed some of these factors associated with fiber bonding. This was published in September, 1950, issue of TAPPI (*2*). The principal purpose of the paper was to stimulate thought and activity in the field. The following statement appears in the section entitled "Future Work":

"Before concluding, I should be remiss of I did not speak pointedly to the need for more study and for more knowledge in the field of fiber bounding. It seems to me that we need coordination and integration in our attack on fundamentals related to all of the components and to the aggregate of papermaking fibers.

"We are getting far enough along with our work on cellulose to worry quite a bit about crystalline and amorphous forms of cellulose. Our lignin work is coming along fairly well in terms of chemical composition, but the physical studies and the effects on fiber bonding leave many challenging avenues of study open to us. One of the greatest unknowns seems to lie in the realm of hemicelluloses. Our analytical methods are inadequate and our understanding of the composition and behavior of the hemicelluloses are incomplete. Our kraft pulping process, noted for its production of high-strength pulps, is really destructive and devastating as far as hemicelluloses are concerned. We dissolve out some desirable hemicelluloses and we create less desirable ones by degradation of the alpha portion. Our analytical methods cannot adequately distinguish between these two types of materials which are rather similar chemically.

"Thus, although much more work is needed in all these fields, the lack of information relating to the hemicelluloses appears to be outstanding —and essential to solution of the fiber bonding question.

"Another great need is the development of analytical techniques to be used to determine the composition and reactivity of fiber surfaces rather than of whole fibers.

"In conclusion, the vital importance of this question of fiber-to-fiber bonding to the science and technology of pulp and paper-making cannot be over emphasized."

Before leaving the subject of pulp testing, I should like to make one general observation. In some of our testing there is a need for the development of what I would call "dynamic" tests as opposed to the conventional "static" tests. To illustrate the point, let us consider the test for pitch in pulp. Pitch, like some of the other organic components of our pulps and pulping liquors is unstable when subjected to some of the extracting, purifying, and drying operations involved in conventional analyses. Thus, by the time we isolate the component in question it probably has changed either physically or chemically or both. This makes it difficult and often impossible to relate the cause and the effect in a given situation. With increased emphasis on simultaneous, or at least combined physical and chemical analyses, and a greater use of "dynamic tests," progress in the field surely will continue.

Control Testing of Paper Making Operation

Let us move along to the subject of control testing in the paper making operation. This, like pulp making, has advanced through a process of evolution toward an increasingly well controlled operation. With literally dozens of variables existing on the average paper machine and with only a relatively small number of these measured in most cases, a high degree of judgment and corrective manipulation is required of the operators. With the increasingly close tolerances involved in modern paper making, there is a real incentive to utilize instrumentation and automatic control in as many ways as are practically feasible.

Before going further into the control of paper making, let us take one step backward, and pick up the pulp where we left it coming from the pulp mill and look at the intermediate step, stock preparation. It is here that the pulp furnishes for the paper machines are compounded. Various pulps and

other additives are combined and blended. The keynote of the operation is uniformity and control of quantities, proportions, and consistencies. A certain amount of testing is essential to the realization of this objective.

The re-use of broke in the furnishes is sometimes regarded as a necessary evil and given very little attention from a control standpoint. The result is usually difficult, troublesome, or even disastrous operation. A vicious cycle is possible in which the failure to give proper control attention to the broke problem leads to the making of more broke, and so on. Because the broke has already been through the system once, variations in its re-use may upset the paper making operation even more than variations of a similar magnitude in some of the virgin pulp components of the furnish.

The mechanical refining operation, in many mills, is not given very close scrutiny from a control standpoint, though the situation is improving.

In general, the throughput is determined by paper machine demands. Consistency is controlled automatically to a greater or lesser degree. Temperature and pressure are somewhat dependent variables. Speed may be fixed and the refiner setting manipulated to give a certain reading of the ammeter on the refiner motor. The desired reading is changed from time to time depending on occasional freeness tests and known changes in furnish or in end results required. Some, of course, are doing much more than this. Fiber fractionation tests and strength tests before and after refining are useful supplements. The paper machine operation and the quality of the paper made remain the most critical and continuous indirect overall tests of refiner operation. However, they involve many other variables which may cloud the issue. On a longer range basis there is an increasing use of such ratios as horsepower-hours per ton of pulp processed per unit freeness drop or strength developed and also the ratio of percent fiber length decrease. These are used to indicate suitability of tackle, need for maintenance, and the like.

Too often the effects of a lack of adequate control and testing, in connection with stock preparation, are all negative. It is hard enough at best to build up the quality in an average or poor pulp but it is very easy to ruin a good pulp. The economic implications of proper refining are very large indeed.

You probably know by now that the converter finds it easy to assign some of his troubles to the paper maker, the paper maker does the same for the pulp maker, and the pulp maker points to the wood. This is human nature and sometimes it is justified. These people are specialists and sometimes they have little appreciation of the problems in other phases of the process. You men, however, in the technical field, have the opportunity, the understanding and, the responsibility to bridge over some of these gaps and to lend continuity and efficiency to the overall process. This is particularly true in testing. There are an appalling number of man hours being spent in running tests which are not of much value while at the same time some critically important information is not being gathered.

There is not time to deal in more detail with control testing in paper making. It is all done for one purpose, to permit operation which will result in the production of paper which meets the desired tests and specifications. We should now move along to the subject of testing the finished paper.

Testing the Finished Paper

A pre-requisite to testing and specifying paper is the development and definition of a common language, an agreement on the use and meaning of terms, and the evolution of a universal nomenclature. Without this common ground where a meeting of minds is possible, there would be chaos indeed.

One of the greatest contributions in this direction has been "The Dictionary of Paper" *(3)* which has come out under the auspices and direction of the American Paper and Pulp Association and which was edited by Dr. Clarence J. West at the Institute of Paper Chemistry. It is interesting to note in the First Chapter, entitled "Philosophy of Definitions" that there are four different bases for defining paper: (1) on the basis of its history, (2) in terms of its use, (3) by its physical and chemical behavior and (4) by its position in the market structure. The latter was abandoned and a combination of the other three was adopted as the best answer to the problem. Another source of such information is a booklet prepared by Committee D-6 of ASTM entitled "Paper and Paperboard Characteristics, Nomenclature, and Significance of Tests," October, 1944.

In our technical training we are sometimes prone to over-estimate our ability to define all papers in terms of the tests with which we are familiar. A brief quotation from the "Dictionary of Paper" on this point is appropriate:

> "Papers can be defined by their physical and chemical behavior. That is to say, they have certain measurable characteristics, both fundamental and secondary, and the record of these characteristics tells the story. The procedure of definition in this case is first to gather the elementary data of weight and thickness, which may or may not be related to behavior but which at least give perspective. Next, the paper is examined as a structural and optional phenomenon, as an object capable of withstanding certain stresses or strains, in short, as a clinical specimen. It has a certain tearing and bursting strength, a certain folding endurance: it has a given gloss, color, opacity, porosity, compressibility, and so on.
>
> "From a scientific standpoint, this form of definition is more appealing than the others. There are, however, some difficulties in this approach. Data of this sort are not particularly revealing to the layman unless they are comparative and unless they can be related in some way to functional requirements. Unfortunately, present knowledge does not always permit one to predict the behavior of paper in use. In addition, there are certain characteristics of paper that are completely subjective or personal in their evaluation. "Appearance" or "quality," for example, are elusive references that are essentially esthetic in nature. Furthermore, there is the danger of misinterpretation by inexperienced users, who would feel that a description based solely on paper properties could be used with impunity for specification purposes."

Another milestone in the paper testing field has been the activity sponsored by the Instrumentation Committee of the American Pulp and Paper Association. This work was stimulated in the middle thirties by the Paper Industry Authority and the N.R.A. These studies have been reported from time to time in the trade literature.

The objectives of this work were: (1) to develop sound instrumental methods for the measurement of those properties essential to grading activities and not covered by existing methods, and (2) to examine existing instruments objectively. The purpose of the latter was to determine the degree to which a given instrument measures the property or properties it is said to measure and to discover and point out any sources of instrumental error which should be taken into account by the user in his interpretation of results and which may be considered by the manufacturer in possible improvements in the instrument.

These studies cover many instru-

ments and methods and are well worth reading if you have not seen them.

In the first instrumentation report *(4)* the job of classifying and enumerating paper properties is discussed. It is pointed out that all properties of paper can be arbitrarily grouped as, "structural, optical, surface, and physico-chemical." The classification of Doughty is recalled as consisting of three groups of fundamental properties; dimensional, compositional, and structural.

The following statement concerning the fundamental and the use properties of paper is given in this first instrumentation report:

"When a sheet of paper is considered as an entity, as a single unit, and not as an aggregate of smaller units, it possesses several properties which are distinct and definite, and which cannot be factored into component properties. These are the properties that are considered fundamental in this report. They are:

Thickness
Weight
Apparent density
Expansion and contraction
Surface contour
Formation
Porosity
Wettability
Dielectric strength
Thermal conductivity
Electrical conductivity
Light transmission
Light absorption
Reflectance
Elasticity
Stretch
Compressibility
Hardness
Stiffness
Bending strength
Tensile strength
Shearing strength

"There are several other evaluations commonly made on papers, evaluations which are normally considered as measuring specific properties, but which are actually affected by two or more fundamental properties, and which do not logically fall under the classification of fundamental properties. These factors are closely associated with the use requirements of the paper. The methods for their measurements have been in the main developed by simulating use conditions. The term "use properties," therefore, seems a satisfactory name for this group of measurements. It must, however, not be considered as including all properties that are direct measures of use requirements. Since many of the fundamental properties are a direct measurement of ability to meet use requirements, the grouping seems to remove from the fundamental properties those which are the result of a combination of fundamental properties. The failure to make this distinction has been the cause of much confusion in the application of testing instruments and the interpretation of testing results.

"The evaluations so classed are:

Bulking
Absorbency
Degree of sizing
Resistance to penetration by liquids
Water vapor permeability
Resistance to wear
Erasability
Rattle
Abrasiveness
Finish
Smoothness
Gloss
Fuzz
Transparency
Opacity
Curl
Bursting strength
Folding strength
Tearing strength
Creasing strength
Permanence"

Selection of the Testing Instrument

If a new instrument which is about to be placed on the market is checked by such a group before going into general circulation, its strong and weak points can be determined and improvements can be made before general sale is begun. Much time and expense is saved over the situation where an instrument's weak points lead to later revision and confusion in the industry.

A critical approach to testing problems is of value to technical men like yourselves. In the case of any paper testing method or instrument, it is well to ask oneself the following questions:

1. What property or properties is this supposed to measure?
2. How well does it measure such property or properties?
3. What is the accuracy and precision of this test?
4. What is the normal variability in the test results due to sampling, due to the instrument, and due to the operator? What is the expected range in overall variability?
5. What precautions must be taken in the test and how often should the instrument be calibrated?

Effect of Relative Humidity

No discussion of paper testing would be complete without some mention of the effect of relative humidity. The results of paper testing are so dependent on relative humidity that the paper must be conditioned and tested in an air conditioned space in the case of all referee testing as well as for much of our control testing. Any departure from the specified conditions of temperature and humidity should be noted in reporting the results of paper testing. Otherwise serious disagreements and misunderstandings may arise.

Paper Testing

Time does not permit any detailed consideration of individual paper tests. There are nearly eighty methods listed in the TAPPI Standards and you are undoubtedly familiar with many, if not most of them. There are current developments and improvements in many of them from time to time. The trend is toward more thorough and more accurate evaluations.

Some theories expressed by Dr. B. Steenberg of Sweden and others as to paper strength and the visco-elastic behavior patterns, illustrate the trends in these matters. More and more emphasis is being placed on high speed stressing of paper during testing. Also, more attention is being paid to the behavior of a specimen prior to the break or failure point. Too many of our tests arbitrarily rely on complete failure for the end point of the test without regard for what happened in the lower ranges of loading.

In order to interpret properly the results of paper testing activities, we must consider and understand several factors which influence the variability, accuracy, and significance of the data. We might list the following as the principal factors:

1. Variability of the paper being sampled
2. Sample size
3. Conditioning the sample before testing
4. Errors of the method
5. Instrumental errors
6. Personal errors

As far as the normal variability of paper is concerned, you know of its heterogeneity, its directional characteristics, its two-sidedness, its variation along the paper machine. These factors must be kept in mind.

In addition, we have an added complication in the size of the sample tested. The smaller the test area, the more the normal variations in the sheet are going to increase the variations in the individual test results. For example, in testing basis weight, a common sample area is 10 sheets which measure 10 to 10 inches, a total of 1000 square inches. This is equivalent to 6,450 square centimeters. On the other hand, in the fold test, the actual area under test for one specimen is of the order of 15 by 2 millimeters or 0.3 square centimeters. Ten specimens give us a tested area of 3 square centimeters. On this basis, 3 square centimeters for the fold test and 6450 square

centimeters for basis weight, the sample size in the latter is 2150 times as large as the former.

One of the instrumentation studies (No. XXVI) *(5)* deals with this problem and gives some data on the percent probable error for the various tests. This gives one a general idea of the trends. You can make similar analyses for yourselves of the specific problems which you may encounter when you are out in the industry.

Conditioning problems vary with different types of paper and paperboard. The important thing is for you to be aware of and to understand the typical response of paper products to changes in relative humidity, and to understand the hysteresis effects associated with the absorption and desorption cycles.

Modification of the standard conditioning specifications for control testing can be tolerated for some tests, while for others it is very dangerous. In any case caution should be exercised in this regard and the actual conditioning history reported along with the results if the conditioning is non-standard. Too many investigations of disagreement in test results have revealed that standard methods were followed except for one very important detail, conditioning prior to and during testing.

Errors in the method are often the most easily overlooked source of trouble. Because of the empirical nature of many of the tests, such as sizing and porosity, it is easy to overlook or forget the limitations of the methods when they are applied to various papers.

We have come a long way from the crude methods which were all that the papermaker had at his disposal for many years. You have at least heard about, if you have not seen, some of the older methods such as tearing and popping paper by hand, giving it the tongue test for sizing, and blowing through it for porosity.

Instrumental errors are potentially or actually present in almost every testing instrument. For this reason, constant and continued vigilance in calibration and adjustment are required, as well as an appreciation of the inherent errors uncovered by such investigations as these Instrumentation Studies. Inertia errors in the pendulum type tensile tester are but one example of the sort of thing one encounters.

The personal or operator errors are always with us. "To err is human." All we can do is to make every effort to secure honest, impartial, careful operation of the testing equipment, with a certain amount of cross checking to catch the unintentional as well as the intentional errors which may creep in.

Attention to and appreciation of the factors just enumerated will lead to the maximum utility and dependability of the results and will permit the drawing of more valid conclusions.

Specifications

There is not much we can say about specifications without going into too much detail in the time remaining. We can say in general, that the most satisfactory specifications for paper are those which define its functional qualifications. This leaves it up to the paper maker to use any combination of available pulps and to exercise his skill and his ingenuity to achieve the desired results. This is in contrast to the "recipe" type specification which dictates the raw materials and processing methods.

Conclusion

Let us review briefly the ways in which you may be involved in paper testing and specifications in your future work.

First, you may be a buyer of paper. Second, you may be a seller of paper. Third, you may be a paper maker. Fourth, you may be in technical work concerned with:

(a) The control of operations;
(b) the setting up of the control standards for existing or new grades; or
(c) the results of research and development studies

Fifth, you may encounter the whole field of raw materials and control testing in connection with the pulping and other auxiliary operations which support paper making.

The better we can define and test the important characteristics of paper (and of those component materials and processes which determine the quality of the finished product), the more economic and technical satisfaction we will derive from paper testing activities. Also, the simpler and more effective will be the whole problem of specifications for the purchaser, the seller, and the manufacturer.

As we look back at this field, it is apparent that we have come a long way and that much progress has been made. As we look ahead, it is equally obvious that we have a long way to go and that a tremendous amount of additional work is needed. Therein lies a real challenge for you technical men, for the fruits of your labors will be measured on these "yardsticks."

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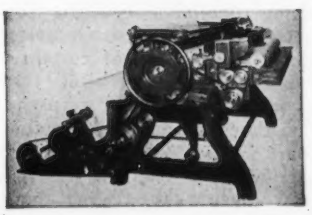

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Paper Converting

Charles W. Stillwell[1]

Ph. D. Cornell University, 1926; Assistant Professor of Chemistry, University of Vermont, 1926-1929; Associate in Chemistry, University of Illinois, 1929-1933; Department Head, Chemical Research, Dennison Manufacturing Co., 1934 to present.

Introduction

Since this is a course in papermaking it is quite proper that the subject of finishing and converting should occupy only a small portion of the time. However, the fact that only one period is devoted to this subject is not to be taken as a measure of its relative importance in the paper industry. If finishing and converting are taken in their broadest sense to include sheet cutting, slitting, and bag making, then it may be safely said that without the highly developed and progressive paper converting industry, the manufacture of paper would be relatively pointless. Very little paper is used by the ultimate consumer as it comes from the paper machine. Its usefulness depends on its conversion into many different forms.

For the purposes of this discussion, finishing is considered to include supercalendering, slitting, sheeting, packing, and similar operations performed at the paper mill. This subject was amply discussed in this course last year by Bancroft and is reported in the *Paper Trade Journal* of November 30, 1950.

The paper converter buys paper from a mill and changes it into hundreds of useable products.

There is an overlapping zone in which the paper manufacturer makes certain finished products normally made by a converter. For some time mills have produced coated papers comparable in quality to coated papers made by converters. However, these are made in a separate operation after the paper is taken off the machine. Their manufacture is, therefore, a conversion operation which just happens to be located in the paper mill.

However, other paper products which used to be strictly converter items are now made on the paper machines. Among these are the so-called process coated papers. Wet strength papers are now made in large tonnage on the paper machines by adding melamine or urea formaldehyde resins in the beater. Crepe, with low percentage of elongation, has been made on a paper machine for many years and is familiar as paper towels.

In the last analysis it is chiefly a matter of economics and quality desired which determine whether creping, coating, or impregnating operations shall be done on the machines or subsequently by a converter.

This discussion will be limited to the activities of the converter with the processes which occur after the paper leaves the mill and with the products resulting therefrom.

It is impossible, and probably inappropriate, to go into the technology of paper converting in this brief time. Because your interest is in papermaking, an attempt will be made to show you why the paper converter is so particular about certain specifications in the papers you will make for him. We shall consider what properties of paper are significant in connection with each of the several basic operations of paper converting.

Certain properties of paper apply generally to all converting processes, and the resulting products. The selection of paper with the proper weight and strength to meet the requirements of a particular process and finished product is obviously fundamental. Less apparent perhaps is the economic importance of close control of weight. A paper converter buys his paper by the pound but almost always sells it by area, whether it be sold in the form of paper cups, napkins, bags, folds of labels, Christmas wrappings, or the hundreds of other familiar paper products. Therefore, if the weight of this paper as received runs only slightly heavier than the standard weight on which costs have been figured, it can make a substantial difference in his operating profits. Close control of caliper is important for all paper which is to be handled in rolls. Variation in caliper results in soft or loose edges which introduce handling difficulties.

For purposes of a more selective discussion of the importance of quality control as related to the basic operations of paper converting, we shall classify all converting into six such operations, namely:

1. Mechanical: Change in size and shape, including slitting, sheet cutting, embossing, dieing out, corrugated board, bags, boxes, tags, labels.
2. Coating: Decorative, functional, adhesive coatings.
3. Printing: A special case of coating in defined areas.
4. Combing: Decorative, functional.
5. Saturating: Decorative, functional.
6. Creping.

Mechanical Processes

In slitting, sheet cutting, dieing out, and any operation involving the cutting of paper, toughness and rigidity are important. Long fibered tough stock or non-rigid, soft, limp stock is much more difficult to cut clean. On some slitters a tough or limp stock tends to crease over instead of cutting clean. In most commercial sheet cutters a certain amount of rigidity facilitates the proper feeding and jogging of the sheets. The difficulties encountered in an attempt to sheet cut extremely limp crepe paper would emphasize the importance of this feature. For dieout operations to get clean cuts, the paper should have an adequate amount of snap or rigidity. It is also important to dieing out that the coating or sizing be free of abrasive materials. In dieing out an intricately shaped decorative label or seal, a supposedly insignificant amount of abrasives can dull the die in such a short time as to make the operation unprofitable.

Embossing requires a bulky stock with the right balance between softness and firmness so that it can be stretched to fill the embossing die and will then hold its three-dimensional position. Embossing is an important factor in the manufacture of fancy box papers and seals.

The manufacture of setup boxes is essentially a combination of mechanical operations. It involves scoring and folding board, forming a box, and applying a suitable covering paper selected to give the desired decorative finish. The control of certain properties of the board is critical. Jute board is selected for high strength where smoothness is unimportant and newsboard is selected for the best smoothness where strength is less important than smoothness. Even though the board is to be covered with a decora-

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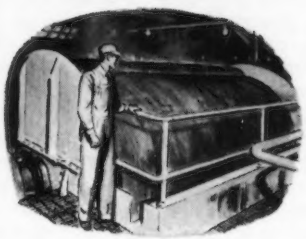

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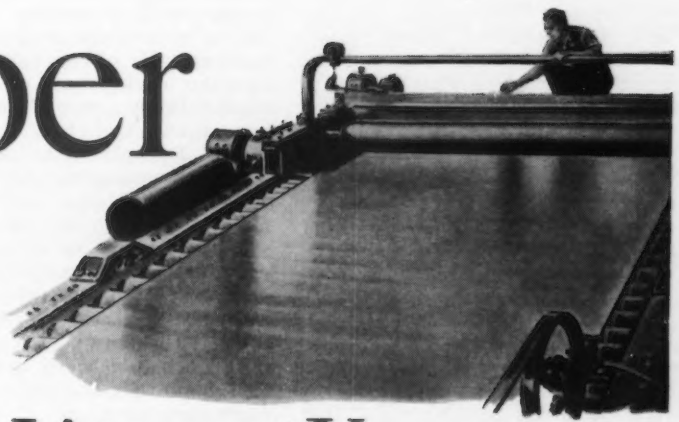

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tive paper when a high degree of smoothness in the outside finish is required, the surface of the board must be reasonably smooth. Rigidity of the board is important in setup boxes, whereas in folding boxes, good folding characteristics are paramount. The board should be clean, to facilitate accurate scoring and folding. Caliper is extremely important in setup boxes. Covers must be fitted accurately, not too tight or too loose, and many times there are several intricate inserts requiring accurate dimensional control to facilitate assembling. Very small variations in caliper will cause trouble in such situations. Likewise, if there is a variation in moisture content, the resulting warping or dimensional instability can be equally objectionable. Certain properties of the cover paper which are important in the manufacture of setup boxes are discussed under the coating operation below.

Coating

Paper is most commonly coated with clay or with whiter pigments, such as titanox, to improve the whiteness and the smoothness of the sheet for printing purposes. This suggests the two basic classifications of coating, namely: decorative coating to change the appearance and functional coating to change properties other than appearance.

Decorative coatings may be applied to change the color of the sheet or to give it gloss, or both. To a complete range of colors, varying degrees of gloss may be imparted by friction calendering, by flint glazing, by cast coating, or by the subsequent application of a film of glossy transparent lacquer. Decorative coatings are also applied to simulate the appearance and texture of other materials. Metallic pyroxylin coating simulates metal. Pigmented lacquer coating, subsequently embossed, simulates leather. A particular dull lacquer finish simulates suede. Cotton and rayon flocked coatings imitate the corresponding fabric velours. There are mica coatings and crystalline lacquers and numerous other special effects obtainable. In general, these decorative papers find their outlets as box wraps and fancy labels and seals.

In all of these, finish is important. When a smooth, level, glossy coating finish is desired, the base stock must be smooth and level. Absorbency is also critical. A uniform formation conducive to levelness and uniform absorbency is desirable. It is best to keep the coating on top of the paper in order to produce the desired finish with a minimum consumption of material. Flexibility is important if the coated papers are to be used for box covers. Absorbency and curling characteristics of the base paper are also important when a coated box paper or a label is to be moistened with an adhesive. On automatic box making equipment particularly it must set up and dry out in a reproducible manner. If a given adhesive is applied to a given size cover paper with given machine adjustments and the absorbency of the paper suddenly changes, the whole drying cycle of the paper will change and cause operating difficulties.

Bulk must be controlled if coating is to be combined with embossing as in many fancy papers. Dimensional stability is important in coated papers which are to be printed.

Functional coatings are applied to papers to make them waterproof, greaseproof, moisture-vaporproof and to make them conductors of electricity or electrical insulators. Photographic papers, blueprint papers, carbon papers, and waxed papers have functional coatings.

For these functional papers the same requirements, formation, finish, and absorbency, are important. It is likely to be more a matter of economics in this area. It requires much less coating material for a given area to lay down a film of high moisture-vapor resistance on a smooth non-absorbent paper than on a rougher more absorbent paper. In fact, with a marked degree of roughness or absorbency it would be impossible because there would always be loose fibers penetrating clear through the film acting as wicks to transfer moisture. Furthermore, the films on the surface of the paper may be more flexible and durable than thicker films which penetrate to non-uniform depth. These thicker films which soak into the paper tend to stiffen it and both coating and paper crack more easily.

The manufacture of a greater variety of improved quality functional papers has been stimulated immeasurably in recent years by the growth of food packaging and particularly the packaging of frozen foods.

Gummed papers coated with a material to facilitate adhesion constitute a large and important special class of functional coated papers. These coatings may be activated by water, solvents, heat, or pressure. For the relatively new classes of heat sealing and pressure-sensitive adhesive coatings made from suitable formulations of a wide variety of resins and plasticizers, the same base paper qualities are important for the same reasons as they are for other functional coatings. For water-activated gummings or coatings, the adsorbency of the paper takes on added significance because if the gumming soaks into much of the sheet, it will not respond to the mechanical breaking process which reduces subsequent curling in variable relative humidities. Uniform thickness across the sheet is also required for the control of this breaking process.

Combining

The converter resorts to the combining of paper to another sheet of paper or another material to produce decorative or functional results. In general, the same decorative effects and the same functional properties are sought as are obtained by coating.

For example, metallic papers to make decorative labels and seals are simulated by coating on a smooth stock a metallic pigment in pyroxlin lacquer, but an actual metallic surface may be provided by combining metal foil to paper. A high gloss finish can be obtained by the application of a suitable lacquer coating, or by laminating cellophane or some other transparent film on the printed or coated color. Grease-proofing or water-proofing may be obtained by a suitable coating, but these properties can be realized to the ultimate degree by combining with the paper a grease-impervious, or water-impervious, film such as aluminum foil or one of the plastics.

Water-proof papers can be made by laminating two sheets of paper with asphalt or some similar material. In this case it is the properties of the adhesive which are depended upon principally to obtain the finished results.

Sometimes two papers are combined simply to get a different texture or color on the two sides. Duplex crepe finds a wide market in artificial flower making because each side is a slightly different color.

Aside from the ever important weight and caliper, combining is also dependent upon finish and adsorbency for these determine how the adhesive film will be disposed in the final product. In general, from an economic standpoint, it is desirable to have a relatively smooth, non-absorbent paper so that the adhesive will stay in the interface where it can function as an adhesive. This becomes important from an appearance as well as an economic standpoint in the case of the asphalt laminated papers where it is objectionable to have the asphalt strike through and discolor the product. In laminating metal foil to paper for decorative box covers or labels and seals, a smooth finish is desirable since a rough finish will show through and make the outer metallic surface rough.

Saturating

This operation also may be performed to obtain either decorative or

functional modifications in paper.

Paper is commonly colored by impregnation with dye, either in the beater or as a converting operation.

Most saturating operations are performed for functional reasons. Paper may be impregnated with mold, bacteria, insect or rodent resistant materials. It may be saturated to impart flame resistance, to produce wet strength or softness. Impregnation of paper with wax for moisture and water resistance is widely practiced.

Wet strength papers are made in large tonnage on the paper machine by the addition of melamine or urea formaldehyde resins. Paper towels, field map stock, etc., are familiar products. Imparting water repellency by the addition of wax emulsion to the beater may also be a small operation, but both these properties are also added to paper economically by converters, particularly when they are wanted in combination with some properties. For example, a wet strength agent combined with one of a number of plasticizers to produce softness, produces a widely used diaper liner paper. A wax emulsion for water repellency, plus softening and wet strengthening impregnants produce a weather resistant paper, used during the last war to make radiosonde parachutes for weather forecasting stations.

The paper curtains which have become familiar in recent years are impregnated with a hygroscopic plasticizer material since water is an effective softening agent for cellulose.

To enhance strength, glue, resin, or rubber latex may be added to paper. Whereas glue without an added plasticizer will stiffen paper, latex serves to make it tough, more flexible, soft, and abrasion resistant so that it finds wide use in the shoe industry and as a base for artificial leather.

For an impregnating operation the converter is interested in absorbency and formation (i.e., uniformity of absorbency). In this case he usually wants relatively high absorbency so that a maximum amount of modifying material may be added.

Recent studies indicate that the degree of hydration of a paper stock has an important bearing on the amount of wet strength which can be imparted to it. It is believed that the resin added actually wet strengthens the gelatinous cementing material between fibers resulting from hydration and a given amount of resin produces much less wet strength in a less hydrated stock.

Creping

The first crepe paper was made about fifty years ago. At that time colored tissue paper had been in use in this country for a few years and was used primarily for making party favors, paper flowers, and the like. In order to be able to mold this tissue into various shapes, it was found advantageous to crinkle it. This prompted the development of a method for creping as we know it today.

When a piece of paper is creped, it acquires several valuable properties. It can be stretched and therefore molded and made to conform to irregular surfaces. It also becomes much more resistant to tearing and puncturing because it can expand and not be ruptured until all the available stretch is removed.

Up to the end of the last war, crepe paper could be roughly classified into two widely different categories. These were the colorful and familiar decorative crepe purchased in folds in stationery and variety stores, used for window decorating, party decorating, costumes, flowers, and the like, and the heavy coarse crepe used for roofing, building papers, barrel liners, bags, and so on.

The last several years very interesting progress has been made in developing crepe paper adaptable to a variety of other industrial uses.

The creping process consists basically in moisturing a piece of paper with a dilute adhesive which serves to soften the paper and at the same time provide a means of sticking it to a polished, heated drum. When the strength of the adhesive bond is just right, this soft plastic paper can then be doctored off the polished drum in a crinkled form to produce crepe paper. The strength of the adhesive bond at the doctor knife, which is critical, depends upon the furnish, absorbency, and finish of the paper, the nature and concentration of the adhesive and the speed and temperature of the heated creping drum which will determine the degree of drying of the adhesive when it reaches the knife.

The amount of stretch built into the paper depends upon the relative surface speed of the drying drum and the creping drum. If it is to have 100 per cent elongation, the uncreped tissue on the creping drum will be delivered to the doctor blade at just twice the speed at which it is carried away from the blade by the drying drum.

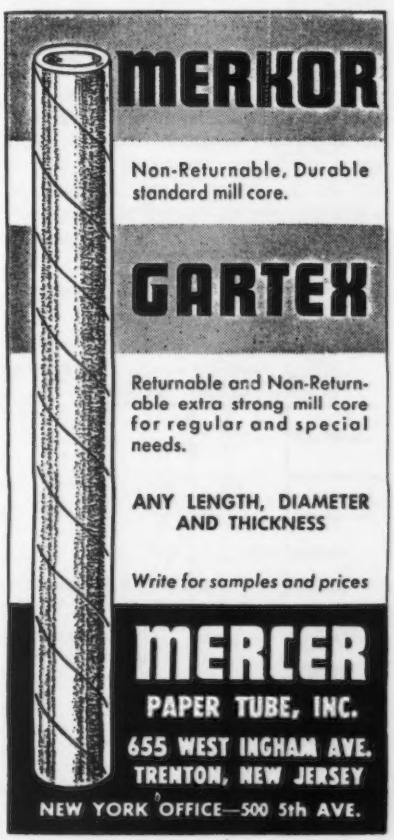
For creping, the converter is interested in a number of properties of the base stock. Finish, strength, and absorbency are apt to be the most critical. To make fine uniform crepe, a smooth finish is considered highly important. The strength of the finished crepe is directly related to the strength of the base paper. While absorbency is always important, it becomes increasingly so as the weight of the paper increases. Other things being equal, it determines how wet the sheet will be when it reaches the doctor knife and this, in turn, will affect the crepe texture.

Absorbency is also important in the coloring of crepe. The color is imparted during the creping operation by adding the appropriate dye to the adhesive solution. Relatively uniform absorbency must be established in the first place to produce uniform coloring and it must be maintained if the manufacturer is to match and reproduce established color standards in his line. Use of a given dye formula with a paper having a lower absorbency than standard would result in a lighter finished color.

Conclusion

In the foregoing paragraph, illustrations have been given suggesting that the control of certain properties of paper by the papermaker are critical to the success or failure of a converting operation. The effective cooperation of the paper manufacturer, facilitating the development by the converter of a steady stream of new or improved paper products has increased our use of paper many fold in recent years.

Today the per capita consumption in the United States is far greater than in any other country.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Finishing and Converting

Baxter L. Wiley[1]

B.S. in Chem. Eng. from University of Maine June 1942. Since June 1942 with West Virginia Pulp & Paper Co., Luke, Md. 1942-1944 Chemist in Maine Laboratory; 1944-1950 Supervisor of Machine Coating Color Making Plant; 1950-1951 Supervisor of Sheet Cutting Department; 1951-Present In charge of Cutting, Finishing, and Loading Departments.

Introduction

The scope of the subject of "Finishing and Converting," generally speaking, covers all the processes to which the paper is subjected after it has left the paper machine until it is shipped as rolls, sheets, bundles, etc., to the customer, who may be a printer, wholesaler, job lot sales or a concern which further converts the product for consumer use.

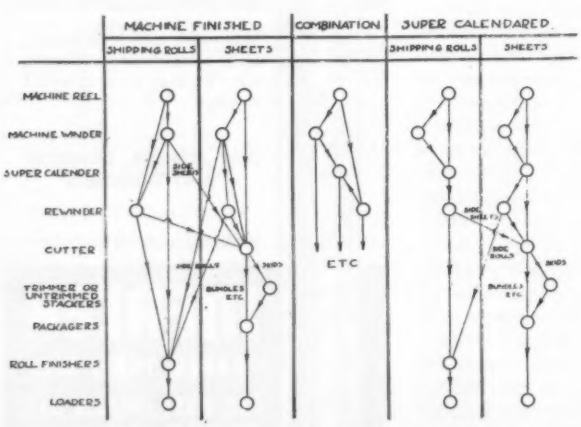
"Finishing and Converting" is a phase of the paper manufacturing industry which has not been studied technically or scientifically to as great an extent as the processes involved in making pulp, preparing stock and manufacturing of the sheet on the paper machine. This is perhaps because of the fact that there is less chemical technology and such highpowered engineering involved. The processes are also less spectacular in that there are no monstrous furnaces or large, high speed machines stretching out for a city block. There is only a group of seemingly routine operations, progressing quietly and usually inconspicuously off in some part of the plant away from the paper machines.

However, this phase of the business is not less important than the manufacture of the paper on the machine. Economically speaking, a mill's success can well depend on efficient operation of the finishing department. The quality of the final product shipped to the customer, the elimination of defective paper and the efficient management of large numbers of employes to keep labor difficulties at a minimum are but a few of the important aspects of the departments.

I expect that up to this time you have studied the various processes involved in making a roll of paper on the machine: cutting the wood, chipping, cooking, washing, bleaching, beating, sizing, addition of fillers and running the final stock over the paper machine, ending up with a roll of paper which must be now further processed before being shipped to the customer.

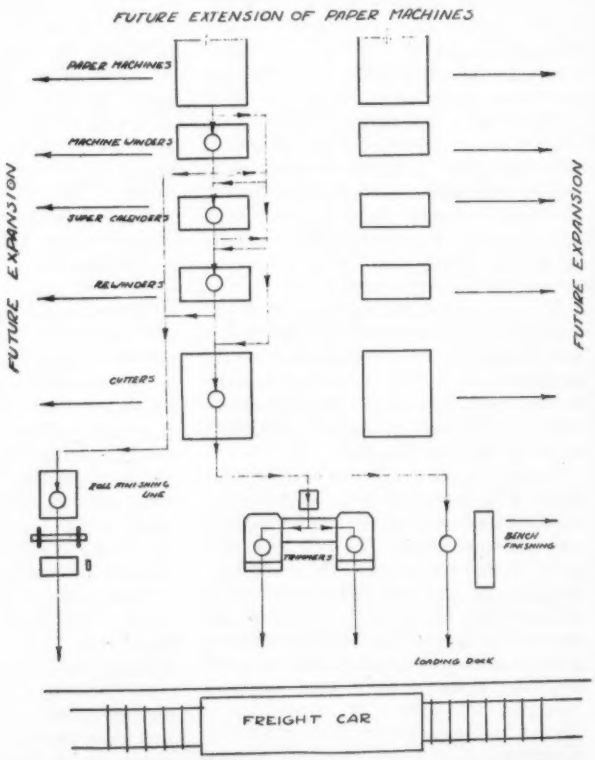
This further processing is our concern at present. The processes involved are: rewinding, super calendering, cutting the web into sheets of

[1] Superintendent of Finishing Department, West Virginia Pulp and Paper Co., Luke, Md.



Flow Diagram showing various combinations of finishing operations.

Figure 1



Layout of finishing and converting equipment showing flow of material.

Figure 2

specified sizes, trimming, packaging, loading into freight cars or trucks and sending the final product on to our customer. First, we will discuss a typical lay-out of a finishing department in the form of a flow-diagram, then taking each operation separately, briefly discuss the equipment involved, what is done on the equipment and finally a brief discussion of comparative costs.

Essentials for Efficient Layout of Converting and Finishing Processes

Figure 1 is a flow diagram showing various combinations of finishing operations. The following are considered essential for an efficient layout of the correcting and finishing processes.

1. Each process should follow in direct line for economy of materials handling and ease of supervision.

2. Aisle space should be sufficient to allow any operation to be by-passed.

3. Ample backlog storage area should be provided behind each operation and tailored to meet the needs of each individual mill. The amount of backlog area needed is usually directly proportional to the degree of specialty by which is meant the variety of grades and packing and thus the variety of combinations of finishing operations.

4. Buildings should be located and designed to allow for future expansion in the directions indicated. Allowance should be made for new equipment to be placed side by side with present equipment. Space should be provided for the lengthwise extension of paper machines, if desired.

5. The amount of each type of converting equipment as well as backlog storage area must also be tailored to any one mill's particular needs. These amounts usually depend on whether the operation is to be carried on during one, two or three shifts during five, six or seven days a week. Again the degree of specialty, particularly with regard to the variety of combinations of finishing operations, is the determining factor.

A high production kraft mill for instance, making only a very small variety of grades in relatively fixed proportions of rolls and sheets each day would probably run all finishing and converting operations three shifts, seven days a week. However, a specialty book and publication paper mill might have all of its converting and finishing operations run during the day shift only, developing backlogs to smooth or average out day to day fluctuations in finishing and converting requirements.

6. Any good layout should allow for materials in process to be moved as simply and cheaply as possible. The layout presented in *Figure 1* could, with the floor inclined slightly from machine to the cutters, be equipped with gravity conveying equipment from the machine winders to the cutter backstands and/or through the roll finishing operation to the loading dock. Individual overhead cranes or a bay crane should be used to service the cutters while electric lift trucks would probably service the sheet finishing and sheet and roll loading operations best.

Lay-Out

Assume a plant is manufacturing paper to be shipped out in the form of rolls and sheets, both coated and uncoated, supercalendered and machine finished. Following with the use of *Figures 1 and 2,* typical order of operations might be:

1. Machine reel
2. Rewound on machine winder
3. Supercalendered
4. Rewound
5. Cut on rotary cutters
6. Trimmed
7. Packaged

7A. Stored

8. Loaded
9. Shipped

All of the above operations may not be involved for a particular order nor is it necessary to follow the processes in the order mentioned. These things are determined by the type of paper being handled, the equipment available at the mill and many other factors too numerous to mention.

Rewinding

The primary function of the rewinding machine is to slit and rewind mill rolls of paper into rolls of uniform density and proper dimensions with cleanly cut edges. It offers a point in the processing to remove defective paper coming from the paper machine, to make proper splices, etc., so the final roll can be processed more efficiently in following operations.

Basically, a winder is made up of the fundamental parts:

1. Backstand or unwinding stand
2. Slitting arrangement
3. Driven drums on which to support and turn the roll as it is winding.

There are many manufacturers of many different types of winders, each having a little different arrangement of winding drums, tension rolls, slitting arrangements, etc.

Some of the common types are:

1. Multiple shaft, center wind system shown in *Figure 3.*

2. One drum, surface wind system shown in *Figure 4.*

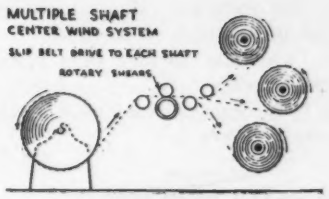


Figure 3

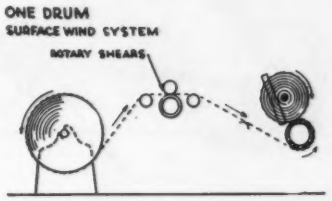


Figure 4

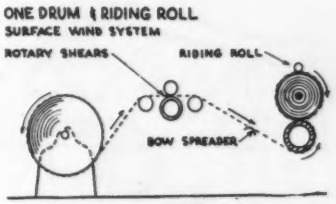


Figure 5

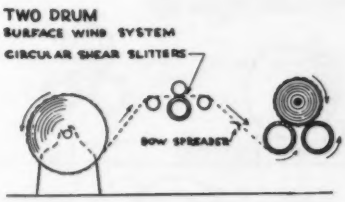


Figure 6

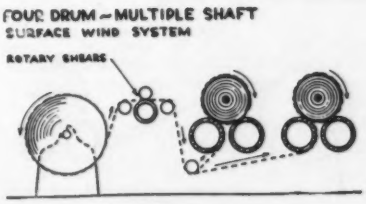


Figure 7

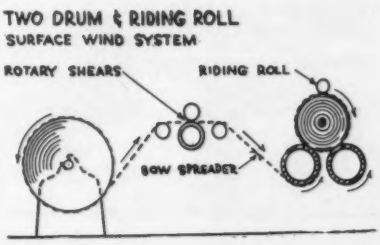


Figure 8

3. One drum and riding roll system shown in *Figure 5.*

4. Two drum, surface wind system shown in *Figure 6.*

5. Four drum, surface wind system shown in *Figure 7.*

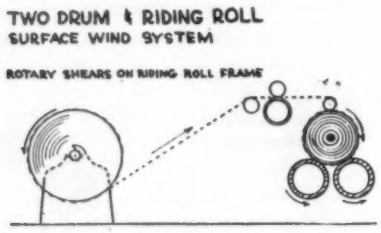


Figure 9

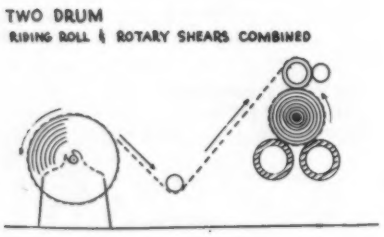


Figure 10

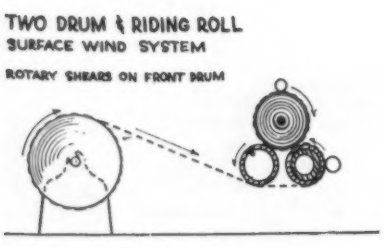


Figure 10A

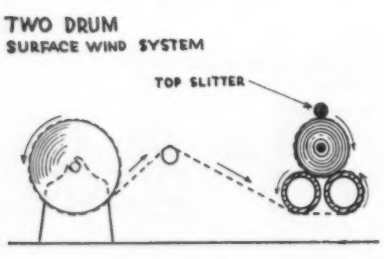


Figure 11

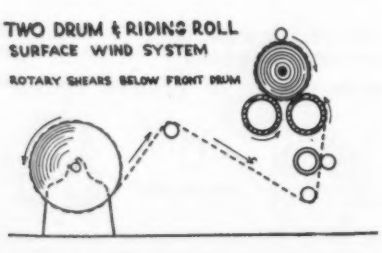


Figure 12

6. Two drum, surface, with riding roll system shown in *Figure 8.*

7. Two drum, riding roll, surface wind system with rotary shears on front drum shown in *Figure 9.*

8. Two drum, riding roll, surface wind system, with rotary shears on riding roll, shown in *Figure 10.*

9. Two drum, surface wind system, with top slitter shown in *Figure 11.*

10. Two drum, riding roll, surface wind system, with rotary shears below front drum, shown in *Figure 12.*

11. Two drum, riding roll, surface wind system, with score cut slitting below front drum, shown in *Figure 13.*

12. Two drum, riding roll, surface wind system, with score cut slitting on front drum, shown in *Figure 14.*

Backstands

There are basically three types of slitting arrangement:

1. *Rotary shear.* In this type, two sharp circular knives, one above the other with slightly overlapping edges, cut the sheet as it passes through the nip. Examples are shown in *Figures 15, 15a, 15b, and 15c.*

2. *Top slitter.* A sharpened circular blade is mounted on a driven roll which is resting on the paper roll being wound. This offers positive separation of the web between rolls but does not make clean cut edges. This type is illustrated in *Figure 16.*

3. *Score cut.* A semi-sharp circular blade is held tightly against a hardened, driven roll over which the sheet passes. The scoring thus effected cuts the sheet. This is demonstrated in *Figures 17 and 17a.*

The part of the backstand which supports the unwinding roll may be built so it will automatically oscillate along the direction of the shaft's axis, at a given rate and for any given amount. Oscillation is used to minimize the build up of high and low caliper streaks in the sheet which cause ridges and buckles in the finished roll.

Variable speed drums are also used to assist in making a more uniformly wound roll with respect to density. This is most commonly used in our own mill and is typically found on the Cameron winder.

The backstand or unwinding stand is arranged in such a manner that it will exert a resistance to the turning of the shaft of paper to be wound. This consists of a braking drum, usually water cooled, which creates a braking action that can be varied to obtain constant tension on the web.

The sheet passes over various rolls, stationary and movable, to spread out

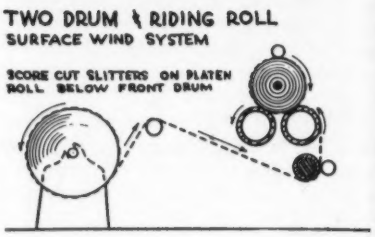


Figure 13

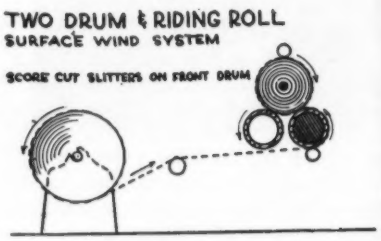


Figure 14

Figure 3 through Figure 14—Diagrams of Various Winder Systems as Labeled

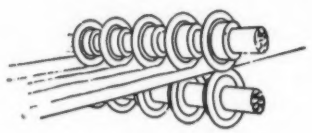


Figure 15

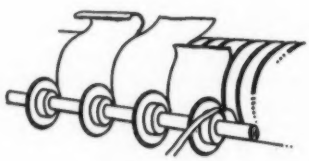


Figure 15A

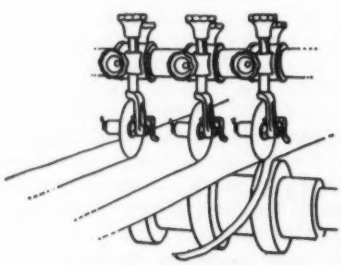


Figure 15B

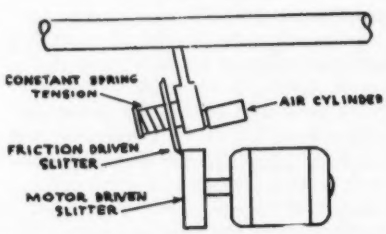


Figure 15C

Figures 15-15A-15b-15c — Types of Rotary Shear Slitters

the web, preventing wrinkles and keeping the web at an even tension. It then goes through the slitting arrangement to the winding drums where the finished roll is built up.

Splices are made with various kinds of tape, such as heat set, solvent type, or glue. A clean, properly made splice is very important when making shipping rolls to prevent break downs in the press which, in turn, is an expensive business for which the mill is sometimes charged if the breakdowns are considered excessive.

I would refer you to a recent article published by Eugene Ward of the Cameron Machine Co., entitled "Slitting and Roll Winding Fundamentals" (1) for more details concerning this important process in paper finishing.

Several rewinders installations are pictured in *Figures 15 through 22.* Two rewinder installations of the West Virginia Pulp and Paper Company are shown in *Figures 23 and 24.*

Supercalendering

The purpose of the supercalender is to impart a higher finish as gloss and smoothness to the web of paper than is possible on the machine calenders.

Machine calenders are made up of a "stack" of steel rolls supported in a heavy steel frame, the bottom roll being driven. Some external pressure other than the weight of the steel rolls themselves can be applied by compound levers and weights or by hydraulic rams pushing down on the top bearing housing. Some control of sheet levelness and finish is possible on this calender by manipulating air pipes to adjust the temperature of the rolls, thereby varying the pressure of the rolls on the paper at various points along the nip.

However, for fine printing papers, such as coated paper, a glossier smoother sheet is necessary. This higher finish is made on supercalenders.

The supercalender "stack" is made up of steel rolls and fiber covered rolls (cotton or paper), sometimes in alternate order. The fiber rolls are sometimes called "bearing" rolls and act in the same manner as an ironing board or the rotating member of an electric ironer. The steel rolls act similarly as the polishing surface of the flat iron and, in the main, gives the high finish to the web of paper. A schematic diagram, *Figure 25,* of a typical high production supercalender for coated paper shows the application of steam showers, fly or blow rolls, doctors, and the location of steel and cotton rolls.

The steam showers add moisture to the sheet to give it the ability to "flow" under the pressure of the nip going through the "stack." The position of the shower and the amount of steam administered is very important in obtaining the proper finish without causing such defects as blackening, blistering or picking. The fly rolls minimize the danger of the sheet wrinkling or blistering when passing from nip to nip.

Some of the variables which affect the finish are the nip pressure, moisture, temperature, speed and type of rolls making up the stack. These are in addition to the many variations possible in the characteristics of the original sheet of paper. Actually the supercalender's results, at best, depend on the quality of the sheet being "supered," whether it has a good formation, properly distributed coating, correct moisture content, resiliency of the fibers in the body stock, uniformity of caliper, surface smoothness, etc.

It appears to be a papermaker's inherent characteristic to expect succeeding processes, such as rewinding, supercalendering and cutting, to eliminate or correct deviations from the aforementioned body stock requirements, particularly unevenness of caliper which may become evident as welts and buckles in the final roll.

The supercalender can make hard and soft places in the roll if there is uneven pressure across the nip down through the stack. The operator can reduce the defect in the sheet being delivered to him from the machine but it appears to be an expensive and never-ending process. The operator would probably use a high speed sander to cut out the part of the cotton or fiber rolls which bear too heavily on the nip, thus relieving some of the pressure at that point. However, if the location of the defect changes in the sheet delivered to the operator he has to start all over again. He may also reduce the amount of steam blowing on the sheet by putting pads over the steam shower at the proper place to block off the steam flow, but he still has to run a reel of paper before he knows whether the bad spot has moved or not.

Supercalenders are expensive machines. The fiber rolls are easily dam-

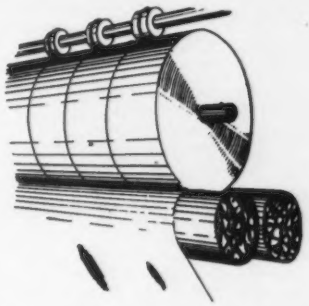


Figure 16—Top Slitter Showing Web Being Slit by Slitters on Riding Roll of Winder

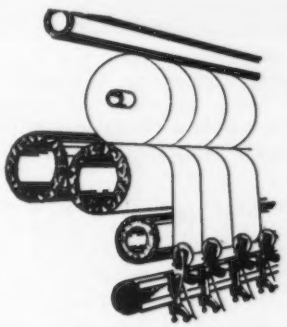


Figure 17—Common Type of Score Cut Slitter

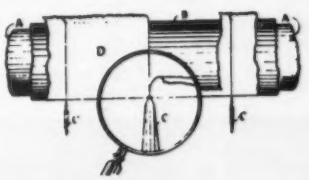


Figure 17a—Edge of a Score Cut Slitter Blade. Note the Relative Bluntness of the Edge against the Paper

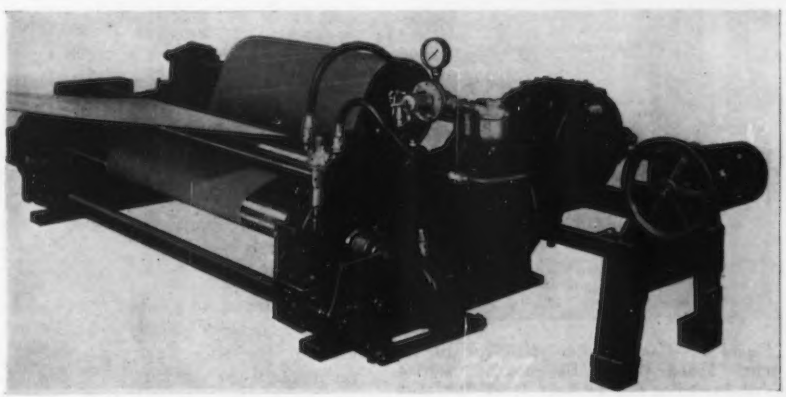


Figure 18—"Camachine" Type "B" Air Controlled Constant Tension Unwind Stand

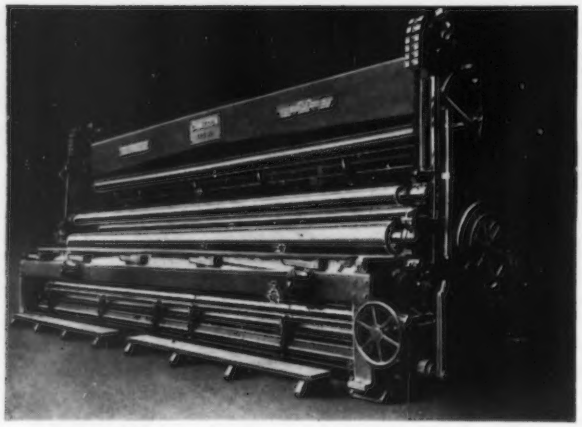


Figure 19—Cameron Rewinder Type 20. This Winder Will Handle Rolls up to 312 Inches Wide, 42 Inches in Diameter, at a Speed of 5000 Feet per Minute

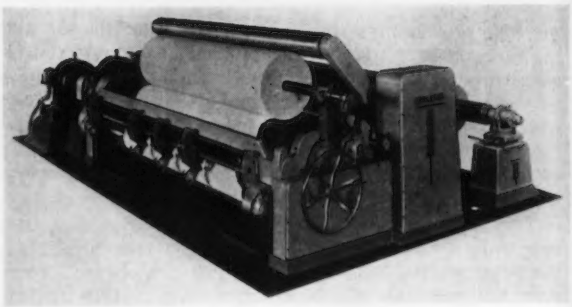


Figure 22—Modern Winder by Appleton Machine Co. (Note Riding Roll Arrangement)

aged and marked by foreign matter going through the nip. If the web breaks when the unit is operating at high speed, the web may form a wad which goes through the nip, often causing deep gashes and marks which will show up when the calender is again put into operation and the web comes in contact with that mark at the nip.

It is very easy to break the web going through the stack; easier than the operator wishes it were. A cracked edge will often break the web under the high pressure and pull inherent in the operation. I have seen a common house fly get into the nip and break the sheet both on a paper machine and a supercalender. *Figure 26* is a photograph of a common house-fly imbedded in a sheet after passing through a supercalender.

If the operator fails to use the tension drive properly, especially when starting up a new reel, the web will snap off easily. Constant and gradual application of tension, pressure and speed are necessary to prevent breaking the sheet.

Lumps in the stock, sticky coating, water spots, slime holes, hair and rope fibers are but a few of the things which cause the supercalender operator a difficult time in keeping up with the paper machine production and, at the the same time, producing a sheet with the desired finish specifications.

When you consider that a modern high speed supercalender, designed to keep up in production with a high speed, wide deckle, paper machine, may cost $500,000, have as many as fourteen steel and cotton rolls weighing from five to twenty tons each, be driven at 300 feet per minute, have pressures at the nip up to 2000 pounds per linear inch, handle a roll of paper weighing three tons, be started up, supered, bad paper taken out, splices made and this all to be done so the operator will be ready for the next reel in about forty minutes; you will realize what a demanding job a supercalender operator has. In addition, he is probably constantly being told to: get ready for another deckle order which means he must sand away the edge marks on the cotton rolls, get more or less moisture in the sheet, correct a curl condition in the sheet, watch out for spots, holes, etc., which are coming, take care of soft or hard spots in the reel, eliminate buckles, calender wrinkles and a hundred other possible defects in the sheet leaving his stack.

I have read in many articles that when one desires a high finish on both sides of the sheet, the web must be run through the stack twice if the rolls are alternately finer and steel. The side of the sheet touching the steel roll is reversed the second time it passes through the stack. Another arrangement of rolls is indicated in which two cotton rolls are run together and about midway down the stack so that both sides of the sheet touch the steel rolls by the time the web has passed through the stack.

This may be true for modern, high speed, large supercalenders but in our own case, by proper application of steam showers and pressure, sufficient gloss is obtained in one pass through a 100 inch supercalender having alternate steel and cotton rolls. This is successfully accomplished on coated papers up to 90 pound basis weight on a 25 x 38 — 500 ream.

In one plant I have visited, supercalendering is being done right on the paper machine, although they are not using as large a unit as we have mentioned. The machine was making coated paper for shipping rolls which were used for magazine printing. This, of course, provides a more economical method of operation because the regu-

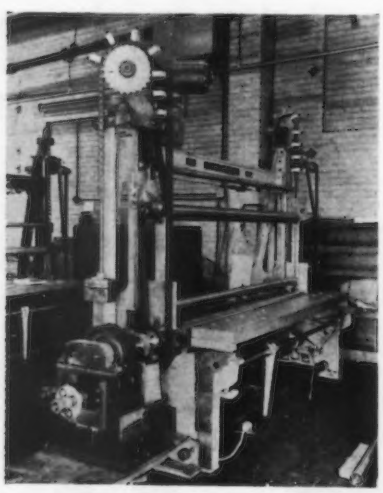


Figure 20—Cameron Rewinder Type 10. A High Speed Winder Designed for Slitting and Rewinding Narrow Rolls. It will Slit Down to a 1/4 inch Strip with Special Slitters. Speed —1500 fpm

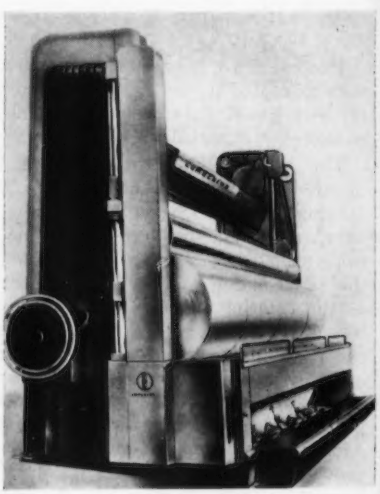


Figure 21—New 234 inch Cameron "Imperial" Winder. Built for West Virginia Pulp and Paper Co., Charleston, S. C., this winder has a 72" Diameter Roll Capacity and is to Operate up to 7000 fpm. Utilizes Newly Developed Hydrair Score Cut Slitters.

lar machine crew is all that is needed. However, it has many obvious disadvantages such as we have mentioned and probably has a lower limit of finish than is possible to impart to a sheet by the conventional method of supercalendering. This is probably not as critical in the case of web or roll printing methods for publication work as it is with paper used for application to high gloss, four color advertising printing.

Uniformity of finish is very important, particularly in sheet paper. This is quite a common variable since, with multiple roll sheeting, if one roll of the group, or a portion of one roll, has a much different finish than the rest, the printer finds nonuniformity in his printed results. Some compensation can be made by press and ink adjustments but after the printer finds six sheets print well and the seventh prints very badly, in that there is no contrast and it is spotty and generally undesirable, he must complain to the mill about the poor quality of paper.

Therefore, a method of indicating the gloss of the sheet as it is being supered would be of great benefit to the operator who, otherwise, would learn only after the roll was finished what gloss he had obtained for that particular roll. Considerable research and experimental work is now being done to accomplish this job and I expect within a few years many supercalenders will be supplied with indicating and recording gloss meters right on the stack.

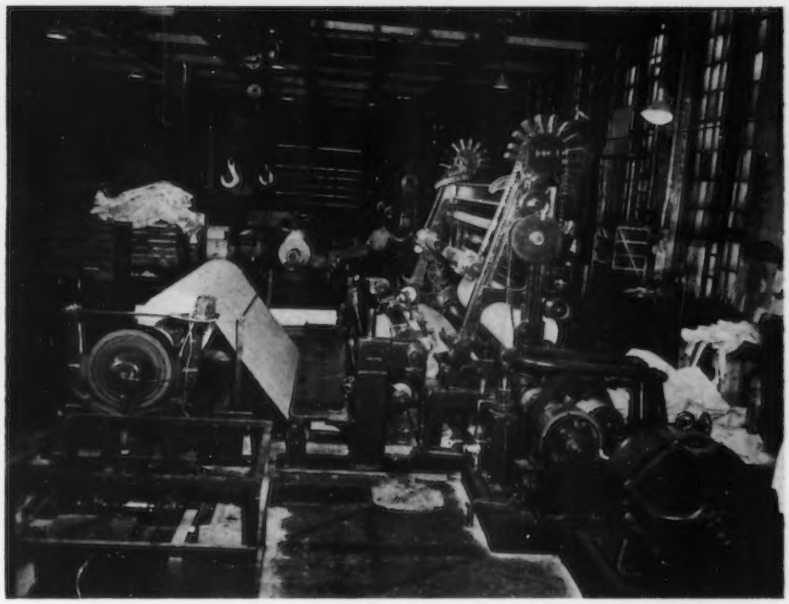


Figure 24—Rewinder Installation at Luke, Md., Showing Variable Speed Drive for Winder Drums, Motor Driven Shear Cut Slitters, Unwind Stand With Braking and Oscillation Mechanism

Figure 27 shows two machine calenders and the reel on a paper machine at the Luke, Maryland plant of the West Virginia Pulp and Paper Company. *Figures 28 through 30* are supercalender installations at the same plant.

After supercalendering, the reel may or may not be rewound before going to the rotary cutters, depending on the type of equipment available and the mill policy for its use.

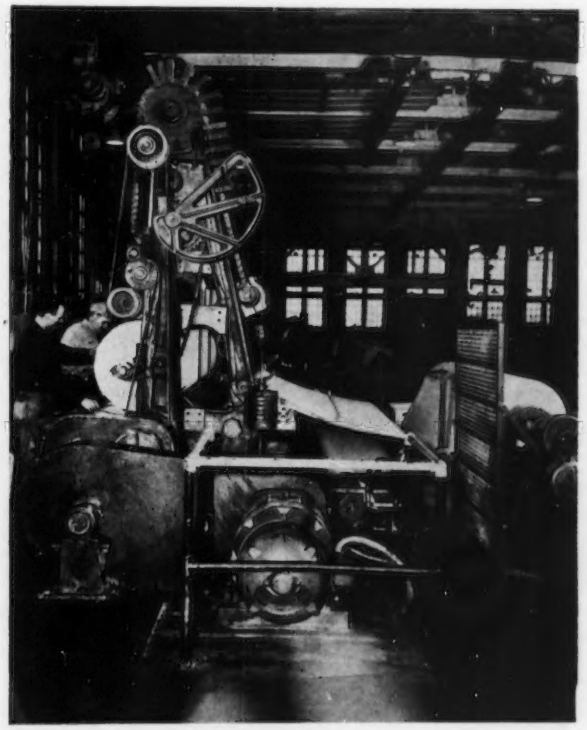


Figure 23—Cameron Rewinder Installation at the Luke, Md. Plant of West Virginia Pulp and Paper Co.

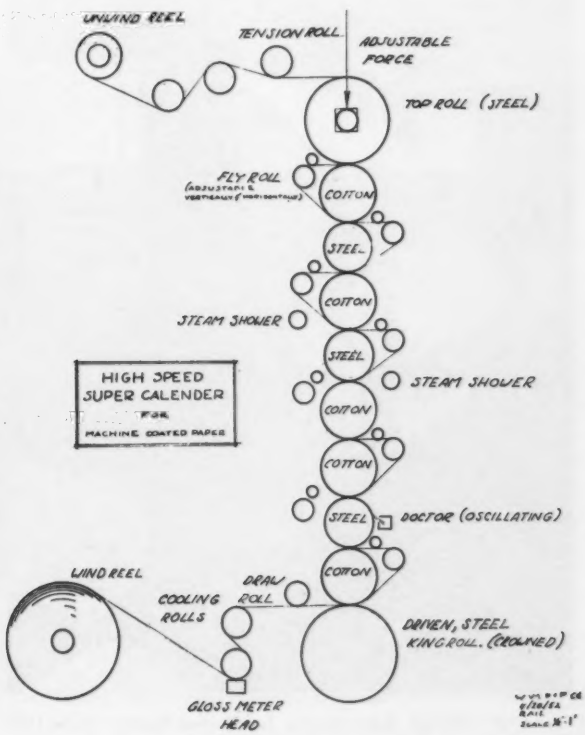


Figure 25

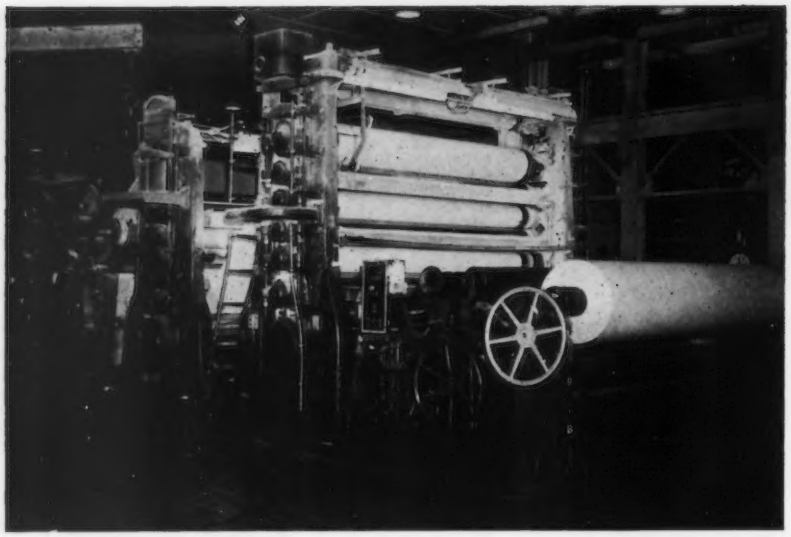


Figure 27—Two Machine Calenders (Steel Rolls) and Reel Arrangement on a Paper Machine

Figure 26—One Hazard in Supercalendering Paper. A Common House Fly After Being Supercalendered

Cutters

A rotary cutter is a machine used to cut the web of paper into sheets of desired length and width. Usually several rolls are cut at the same time by using multiple roll backstands. The elements of such a machine are illustrated in *Figure 31* and consist of:

1. Backstand to hold the rolls. (B)

2. Slitters to cut the web to desired widths. (H)

3. Squeeze rolls to pull the web through to the knife. (I)

4. A driven rotary knife, (F), which gives a shearing cut action with a fixed bed knife. (G)

5. A layboy system to carry the cut sheets from the cutter to a piling and stacking arrangement. (N)

After the web of paper has been wound at the calender or rewinder, it

Figure 28—100-inch Supercalender for Coated Papers. Note Light Colored Cotton Rolls, Method of Weight Application, and Wind Stand

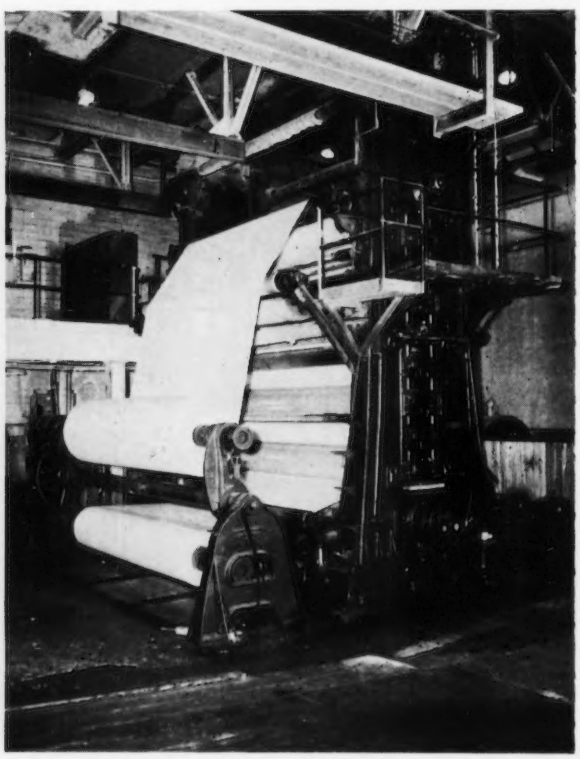


Figure 29—158-inch Supercalender for Coated or Uncoated Papers

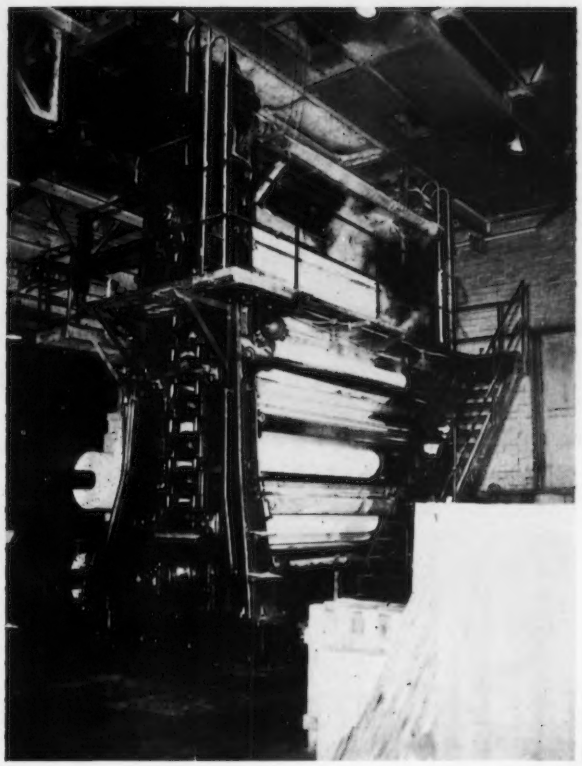
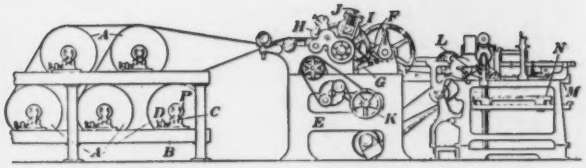


Figure 30—Rear View of 158-inch Supercalender. Note Steam Showers and "Blow" Rolls

is taken to the cutter room. If the reel has been wound on a steel or fiber core, a steel shaft is inserted and held in position with steel "collars" whose lugs are inserted in slots in the end of the core to prevent the reel from turning on the shaft. The rolls containing the shafts are then placed on the backstand, the ends of the shaft resting in open bearings which are equipped with screws so the web can be aligned both horizontally and vertically when fed into the cutter.

Generally, no more rolls will be cut at the same time than to make a total of 450 pounds basis weight, (ie: 50# sheet x 9 rolls = 450#). If more are cut at once, the knife is inclined to make a feathered cut with so-called "whiskers" hanging from the cut edge.

The webs of paper are fed one at a time over guide and spreader rolls, passed under the slitters which determine the width of the sheet and are led into the nip of a grooved squeeze roll and a driven steel drum. Leaving this nip, the web slides down a board at an angle and passes over the steel stationary bed knife. A fly knife, whose variable speed determines the sheet length, cuts the web with a shearing action somewhat like a lawnmower cuts grass but with less of an angle to the revolving blade.



A- Roll of paper. B- Roll stand. C- Edge alinement hand wheels. D- Paralleling adjustment hand wheels. E- Cutter frame. F- Revolving knife. G- Stationary bed knife. H- Slitter knives. I- Squeeze roll. J- Squeeze roll adjustment screws. K- Expansion pulley. L- Automatic counter. M- Control switch. N- Layboy table.

Figure 31—Elements of a Rotary Sheet Cutter

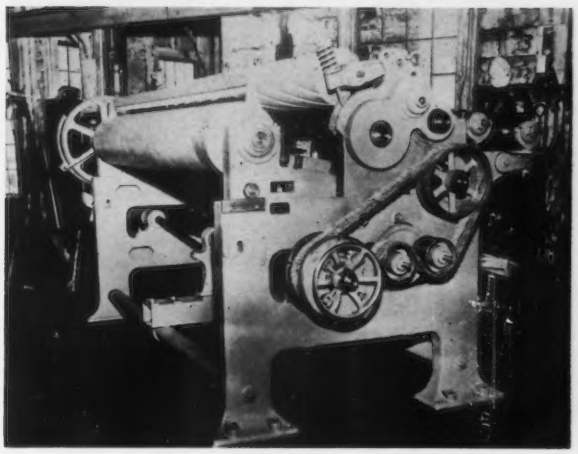


Figure 33—Simplex High Speed Hamblet Cutter Unit. Note Expansion Pulley Drive for Fly Knife

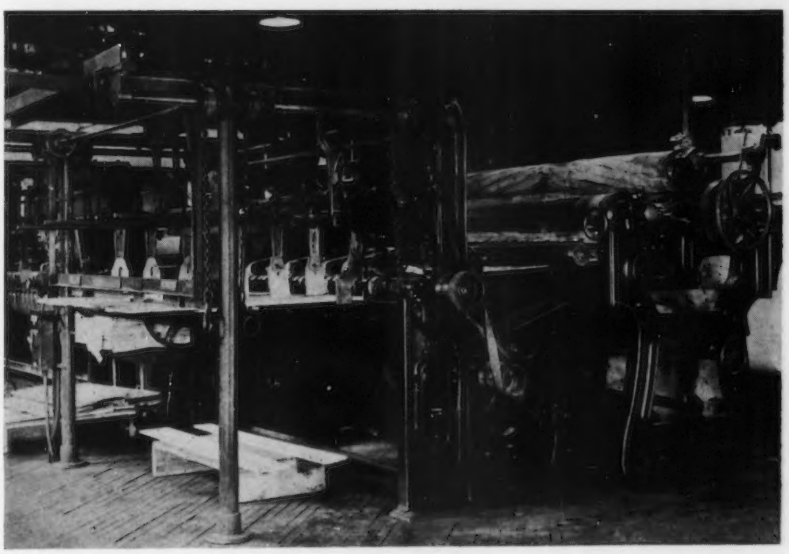


Figure 32—Cutter and Layboy Installation now Displaced by Modern High Speed Equipment at Luke, Md., Plant of West Virginia Pulp and Paper Co.

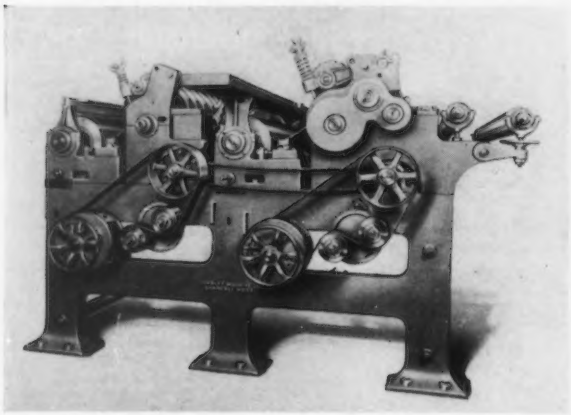


Figure 34—Duplex High Speed Hamblet Cutter Unit for Cutting Two Different Sheet Lengths From Same Roll at the Same Time

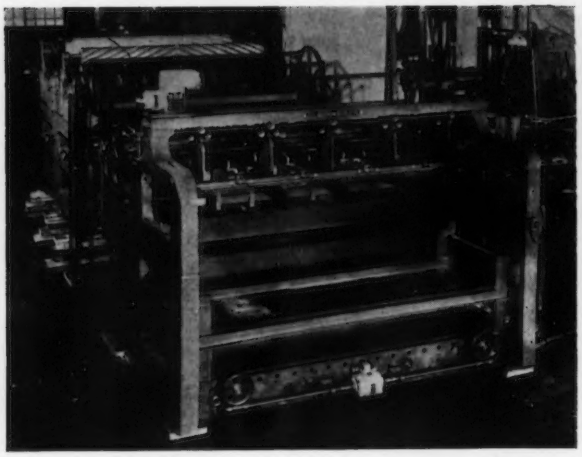


Figure 37—Clark-Aiken Duplex Rotary Cutter and Layboy

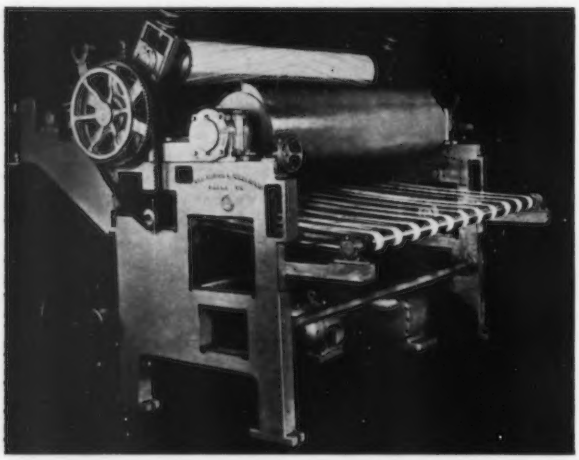


Figure 35 — Moore and White Simplex Cutter Unit With Special Drive and PIV Drive for Variable Speeds of Knife

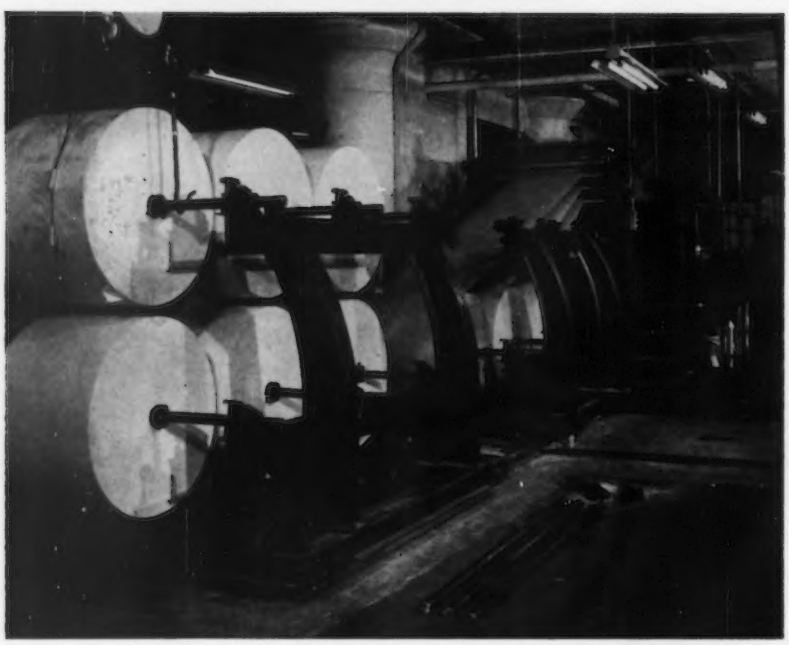


Figure 36—L-Track Movable Backstand Unit for a Rotary Cutter. This Arrangement Materially Reduces "Down-Time" on the Cutter Unit

The speed of the fly knife is set either by an adjustable expansion pulley and a set of gears designed to cover a range of perhaps 18 to 80 inch sheet lengths or by means of a cone pulley arrangement and variable gear ratios. The former method is the more stable arrangement, offering less possible variation in sheet length due to belt slippage.

After the web is cut, it is carried by a tape conveyor system to the piling arrangement called a layboy where it is jogged in place by mechanical paddles to make an evenly stacked pile of paper on the skid.

On simple tadem delivery layboys, a maximum speed is usually 250 feet per minute. At speeds much higher than this, the edge of sheets may be damaged by striking the "stop" at the end of the pile too violently. In order to obtain higher cutting speeds, a layboy with an overlapping arrangement has been devised with which the sheets are made to overlap on the tape system after being cut and while being delivered to the layboy. This arrangement allows cutting speeds as high as 750 feet per minute at the knife while the sheets are being delivered at the layboy at only 250 feet per minute.

Air, either compressed or from a rotary blower, is directed under the sheet to assist in floating it onto the layboy while it is unsupported by the tape system. Air is also used for the same purpose on the overlay system at the point where the overlapping begins.

Overhead tapes are sometimes used to prevent the sheets from flying up and becoming jammed going to the layboy. Either a slight draft, which may be caused by the speed of the sheet being delivered or static electricity will often cause the top sheet to fly up, particularly when passing under the knife. This sheet may then

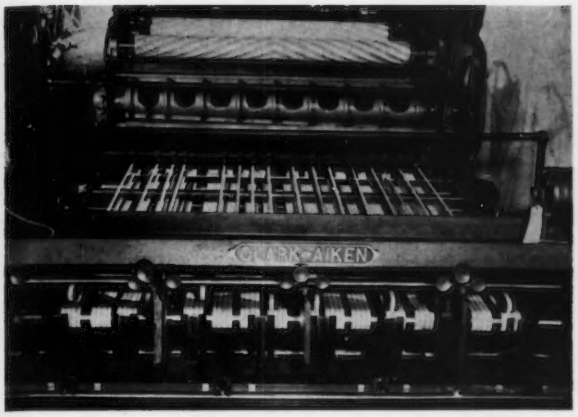


Figure 38—Clark-Aiken Duplex Rotary Cutter. Note Delivery Tape System With "Overhead" Tapes Which Keep Cut Sheets Flat During Delivery to Layboy Piler

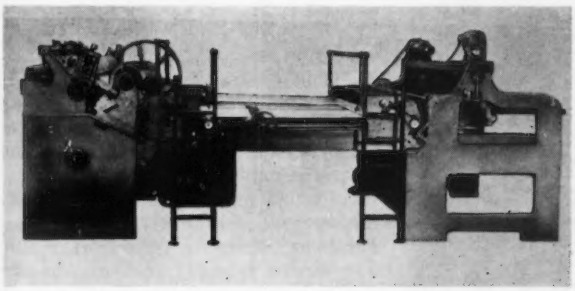


Figure 39—A Side View of a Clark-Aiken Rotary Simplex Cutter and Layboy

fold back and cause what is known as a "dog ear" in the stack on the layboy or may even jam up the tape system completely.

Special wheels, with or without tapes, rest on the sheet just before it leaves the tape system and give a corrugated effect to the sheet which assists it to support itself on its way over to the pile on the layboy. Special metal edge turners raise the edge of the sheet to increase the corrugated effect and likewise to prevent the leading corners of the bottom sheet from turning under, another cause of "dog ears."

Often, to fill out available deckles on a paper machine, it is necessary to make two sheet orders of different sizes, side by side. The resulting reel may be slit on the rewinder so that there is only one size in a given roll. This roll would then be cut on a simplex or single knife cutter. This adds another cost to the job. Consequently, duplex cutters with two knives capable of cutting two lengths of sheets from the same roll of paper are used.

Figure 40—Mamco Continuous Piler Installation With two Piling Stations

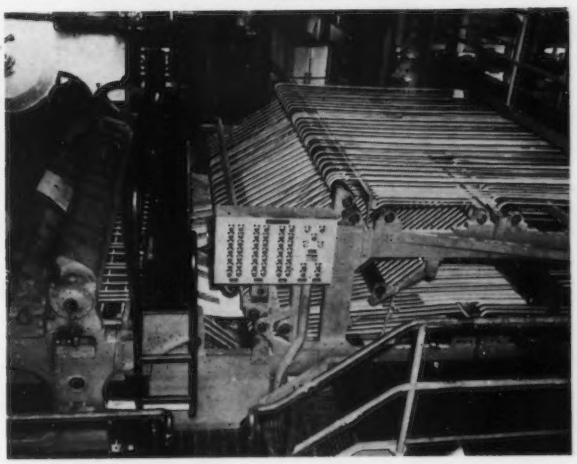


Figure 41—Mamco Continuous Piler Showing Control Panel and Tape Delivery System

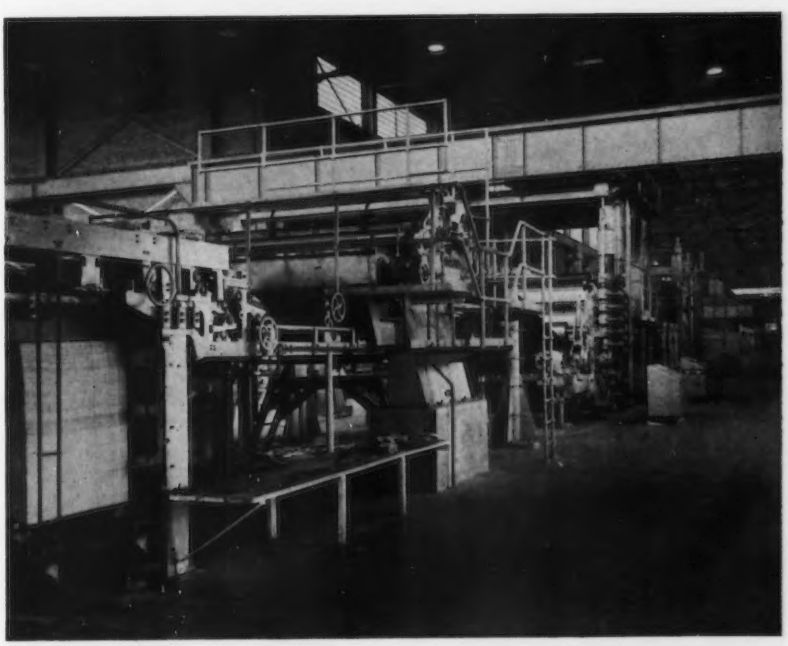


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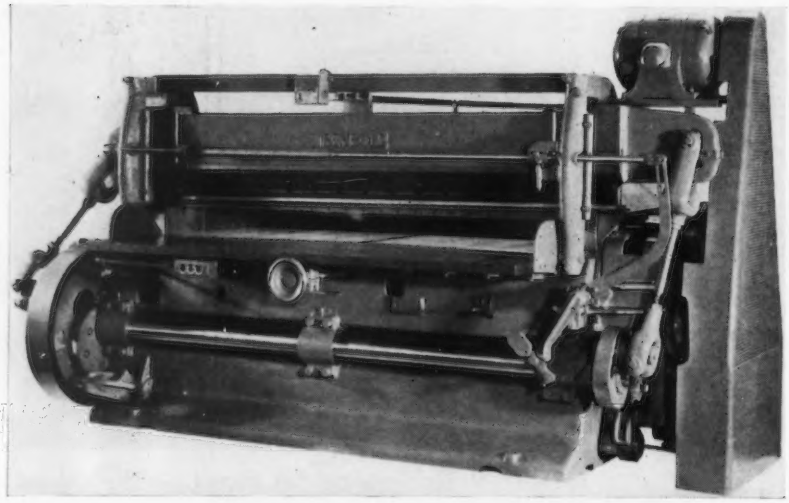
Figure 42—Mamco Continuous Piler Attached to a Beloit Single Type Cutter on a 140 Inch Cylinder Paperboard Machine

Figure 43—Front View of two Seybold Trimmers with Connected Backtable. Skids of Paper Rest on Hydraulic Lift

Figure 44—Rear View of two Seybold Trimmers with Connecting Back Table



←Figure 46—Saybold 94" Mill Trimmer

The duplex or two knife cutter is only two single knife cutters in one machine but requires considerably more ability to operate efficiently. Some mills go to the extra cost of simplex cutting in order to prevent using duplex cutters because of the increased variables. However, with a good duplex cutter and a well trained crew, higher efficiency and much lower cutting costs are possible with duplex cutters.

A word about the organization of the cutter room might be of interest. In my experience of visiting various mills, the standard form of organization seems to be as follows. A general foreman has charge of the operation. Each cutter has one man who operates it but does not set it up for the cutting operation. A girl tends the layboy piling unit. A crew of men shaft up the rolls and load the cutter. A specialist sets the knife and slitters and checks, as necessary, to see that the cutter is cutting the proper size. This arrangement is quite inefficient for many reasons. Our mill had such a set-up until April, 1950, when a complete reorganization took place.

Another and more efficient method of organization might be the following. A *production foreman* places the crews on the job and informs the operator of each cutter what he is to cut next and shows him where it is. He is responsible for the amount of production for the room. A *quality foreman* continually checks and makes sure the cutter operator checks the size, color and other factors relative to quality on his

←Figure 45—Modern Seybold 64" Auto-Spacer Paper Cutter Installation, Kalamazoo Vegetable Parchment Co., Kalamazoo, Mich.

unit. Each cutter has a completely integrated crew consisting of an operator, helper and layboy operator. The operator is responsible for the quality and quantity of paper coming from his cutter. He sets his layboy, slitters and knives for length and square and, with the assistance of his helper, shafts up the rolls for the next load and at the proper time, loads his cutter. Each unit has its own electric monorail crane so that no interference results when several cutters need to be loaded at once. A clerk keeps a record of what the various machines have made for sheets and informs the production foreman of: all the data he must have to decide what to cut next, how many rolls to be cut at a time, what defects to expect, any change in specifications, diversions from one order to another and a great many other details found in such an operation.

Each cutter has its own automatic counter and marker installation which is used to insert tags at every ream throughout the skid. The desirability of automatic counters is entirely predicated on the mill policy of strictness of count in relation to the type of paper made and the way it is handled in the trimming and packaging processes.

The paper is inspected as closely as possible while being cut and defective paper is torn off rolls, thrown out of the skid, or marked for special attention in the finishing room in later processes.

In some cases, cutters are installed on the dry end of paper machines making container board and such types where, instead of having the product in the form of a roll at the end of the machine, it is continuously cut and piled in one operation. New types of layboys have been installed where two layboys in tandem are used to make possible continual stacking of the cut board. They have been built as duplex cutters and duplex layboys with a third arrangement to almost automatically divert defective sheets away from the acceptable piles.

Figures 32 through 44 show some typical installations of rotary cutters.

Finishing Room

Paper from the cutter room is delivered on skids to the finishing room where the inspection, trimming, sorting, and packaging processes are performed.

A paper trimmer with a guillotine knife is used to cut the paper into a four-square block of proper dimensions. A lift of paper in quality of reams up to the knife capacity, approximately eight inches in height, is loaded on the back table of the trimmers. The operator actuates the backboard of the trimmer to bring the cut to the proper position under the knife. By pulling a handle to engage the clutch, he brings the holding press down on the pile as the knife cuts through the paper.

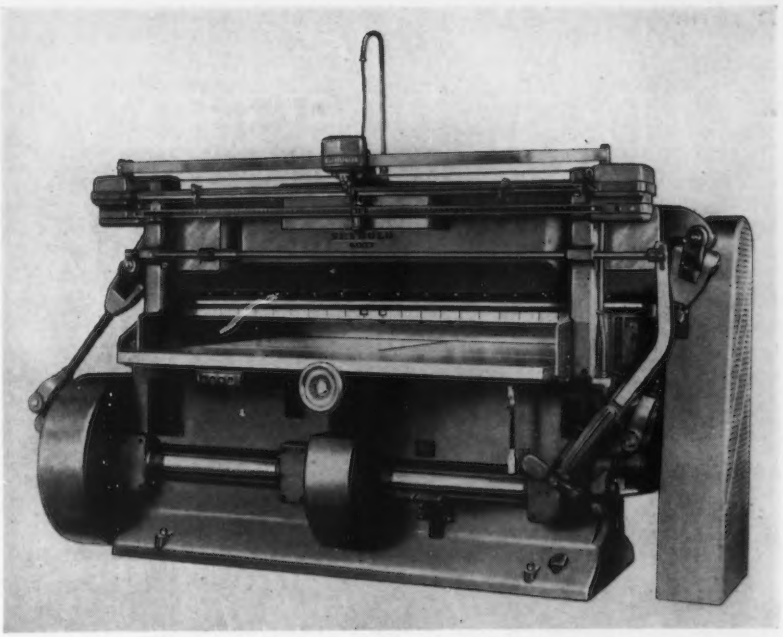


Figure 47—Seybold "Sixty" 84" Mill Spacer Paper Trimmer

A tape gage which indicates how far the back board of the trimmer is from the knife enables him to regulate the back board travel so the proper size is cut. All four sides of the pile are cut. A side rail at a 90 degree angle to the knife and a backboard built parallel to the knife helps the operator cut a near perfect 90 degree cornered rectangle of the block. Often these blocks are split to as many as six smaller sheets. This requires great care on the part of the operator to prevent off-size trimming.

Multiple splitting on a trimmer is usually done in printing plants where the large printed sheets are split up into such items as labels and magazine paper. Special trimmers equipped with automatic spacing devices are used for such work. However, for mill work where most sheets are only trimmed on four sides, the automatic spacing device is not only superfluous but actually shows down production.

In some mills, an operator and helper lift the block of paper from the cutter skid to the trimmer table where they trim the block and then place it on a skid to be wrapped for shipment.

In some cases, two trimmers are connected with a steel table. Two men lift blocks to this connecting table and feed two trimmers from it. The operator must only trim the block and, with his helper, place the trimmed block on the skid to be shipped. Efficiency of the two systems depend on the tonnage per order and whether more through-put is desired per trimmer to keep production equal with that of the paper machines.

Special layouts are often used to handle paper from the trimmer which must be packed in cases or cartons. These special layouts are used principally to reduce the amount of handling of the paper and transporting it to the various work stations. In any such plant, material handling is an appreciable part of the total processing cost and should be kept at a minimum. In addition, each time paper is handled it is liable to be damaged, which adds to the cost of the processes involved.

From the trimmers, the skid goes to scales, where it is weighed and a clerk makes out the proper labels to be attached to the skid. This clerk also keeps proper records of all the paper which crosses his scales. These records are used by the personnel of the shipping department to assist them in grouping orders for shipment and also tells them the weight of each skid as well as the skid numbers.

From the scales, the skid goes to the wrapping and strapping crew, who wrap the skid with waterproof kraft and secure it with gummed tape. A wooden lid is then placed on the top of the wrapped skid and steel bands are fastened around the full skid by means of tightening and crimping machines to secure the whole unit. This prevents disarrangement of the paper in the skid while being transported to the customer.

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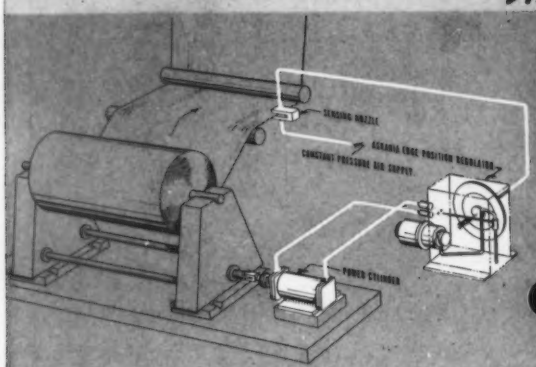

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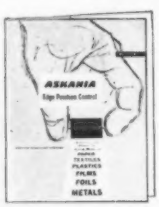

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Generally a portion of the sheet paper is sold untrimmed and often in special packages such as bundles, ream sealed, cartons, 100 sheet sealed, specially wrapped and rope tied bundles for export as well as many other ways. This is usually referred to as "bench finishing" and is normally handled manually.

If appreciable tonnage of smaller sized ream sealed paper is to be handled in sizes such as 8″ x 10½″, 8½″ x 11″, 8″ x 13″, or 8½″ x 14″, an automatic sealing machine is used. The automatic sealing machine will wrap up to 1000 reams of paper per hour and requires specially trained personnel to operate it.

The actual packaging and finishing operations of the product are a very important phase of the paper manufacture. It is here that the final inspection takes place to insure that no defective paper is shipped to the customer. If appreciable sheet tonnage is handled, the finishing room actually has more employees than any other particular department in the production phase of the mill since most of the work is manual. This fact, when considering the concentration of personnel, provides a most fertile field for labor difficulties. It is generally conceded that the personnel-labor relations and supervision problems involved in the finishing room are greater than is the case elsewhere in the mill. It follows that the Superintendent in the finishing room may spend more time and effort with these problems than with the problems involved in the actual finishing process itself.

Figures 43 and 44 show the front and back views, respectively, of two Seybold trimmers which are connected with a connected backstand.

Figures 45, 46 and 47 are photographs of several Seybold trimmer installations.

Roll Finishing

The roll finishing operation is comparatively simple and is often done at the machine winder. The rewound rolls are wrapped with the specified number and types of kraft or waterproof kraft wrappers, wide enough to extend over the edge of the roll for crimping. Cardboard heads are set on and a gummed head sealed over it to keep it in place so that it will protect the slit edge of the roll. Heavy paper board strips are wrapped and glued around the outside edges of the roll to prevent scuffing during shipment. Proper labels and marks are stenciled or printed on the roll and then it is placed in storage for loading.

Shipping

After the various orders are wrapped, strapped, labeled and completed, the shipping department assumes responsibility. The chief clerk in this group is continually working a jig-saw puzzle with a time limit. The planning of consolidation of orders in the same car, meeting delivery dates, ordering cars or trucks, expediting all this and at the same time meeting the railroad's specifications and the customer's due dates keeps him constantly checking and scheduling.

A crew of men load the skids or packages in designated cars in a prescribed manner. The usual load amounts to no less than 36,000 pounds per car. This crew must brace the skids in the car so they will not be damaged in transit. Correct bracing methods use either timbers between the skids at the door of the car and/or steel strap anchored to the floor of the car. This must be done carefully lest the skids shift position during shipment and inflict costly damaged to the paper.

Records and Cost Accounting

A thorough and continuous record of production and costs for each operation is imperative if the Finishing Superintendent can know what the relative standing of the operation is, whether it is standing still, progressing or slipping into higher costs and lower productivity.

Although the mill accounting division normally compiles and submits such cost figures to top management, it is well for the Superintendent to make certain the source of the data is correct as well as to know the method of accounting and presentation of costs to management. In a company having several mills, this thorough knowledge is necessary in order to compare records of costs and productivity with the other mills in the group. There is a great deal of rivalry between such mills in attempting to achieve the highest efficiency.

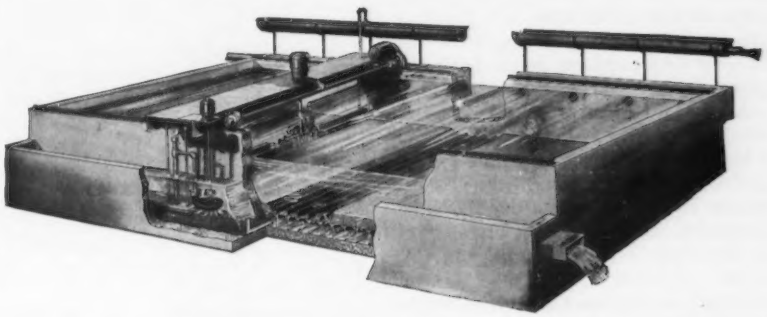
Generally speaking, the common term of productivity is expressed as pounds or tons of paper processed per man hour for each operation. This is calculated as "direct" productivity and costs and as a "total" cost and productivity for a given operation. "Direct" means the inclusion of only those employees directly working on the processing unit. "Total" costs and productivity figures include all the employees working in the division such as the janitors and foremen.

When considering the operations controlled completely by the employees, such as those in the finishing room, it is often desirable to keep a record of each employee's performance in order to spot the employee with a sub-normal record. Thus, it is possible to critically survey the situation, not with the specific purpose of disqualifying that employee but to be able to follow what he does in order to find out if more training or other aid is required.

The cost system should enable the Superintendent to see what his more expensive operations are so he can study them with the object of improving the efficiency.

From a productivity standpoint, each employee utilized over and above the number actually required to operate the equipment is an added burden, so to speak. When one realizes that perhaps as much as 20 percent of the personnel in the finishing room are actually service personnel, one realizes how important it is to keep a close watch on such matters.

The total cost for such a group of operations in a mill producing 7000 to 8000 tons per month, may run as high as $200,000 per month. Even the materials used in packaging the paper may amount to as much as $35,000 to $40,000 per month. Such tremendous costs point out vividly why the superintendent must keep a close record and control of each operation.



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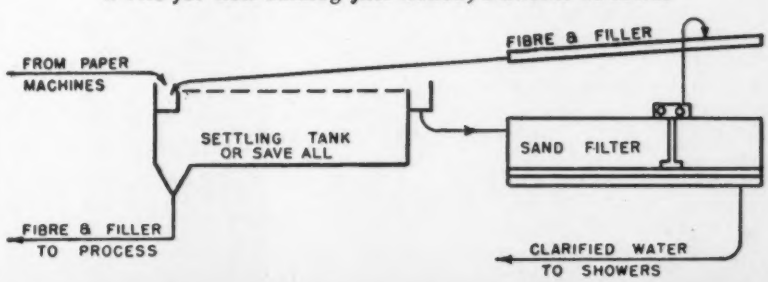

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Introduction

The mechanics of printing can be described most simply as the act of putting ink on paper. It is as simple as that regardless of the seeming complexity of modern printing equipment. Anyone can fulfill this definition of the mechanics of printing with the simplest of equipment and a minimum of experience, as shown in *Figure 1.*

The art of printing as compared to the mechanics of the process, is a horse of another color. The art of printing can perhaps be defined most simply as the act of putting the right amount of ink in the right place. This is demonstrated in *Figure 2.* In this figure we have isolated one unit or element of a printed picture, a highlight halftone dot, and since it is too small to see with the unaided eye I have located its position on this sheet of white paper at the precise center of this circle. This tiny dot of ink is one individual, isolated element of a reproduced photographic image. In other words, it represents the basic element of a printed picture.

Now let us look at the picture in *Figure 3* from which this dot was copied and see if we can identify it, or find what part of the picture it came from since it is one element of this halftone reproduction.

Obviously, looking at the picture as a whole, no such dots are visible on this line screen reproduction, so it will be necessary to enlarge or magnify a section in order to see what these basic elements of picture reproduction are like.

Here in *Figure 4* we can see the actual dot structure of an enlarged section of the half-tone picture. Observation of this enlarged section comprising the detail in the eye of the portrait subject, reveals the method by which an infinite variety of shading from the full blackness of the ink to the pure whiteness of the paper can be reproduced by varying dot structure.

To capture and reproduce the sparkle in the eye of this maiden, and to retain all of the delicate feature detail, and all of the intricate design in the bridal veil, it has been necessary to use about one million halftone dots in various arrangements and various sizes. Thus the reproduction of tone copy (photographs, paintings, watercolor, charcoal drawings and the like) is fairly complex and intricate problem, consisting as we said previously of putting just the right amount of ink in the right place in every part of the picture.

It is my hope, to be able to explain the major steps involved in reproducing various types of copy, and tone copy in particular, by the major methods of reproduction. That is, letterpress, lithography and gravure.

Figure 1
Ink Drawdown

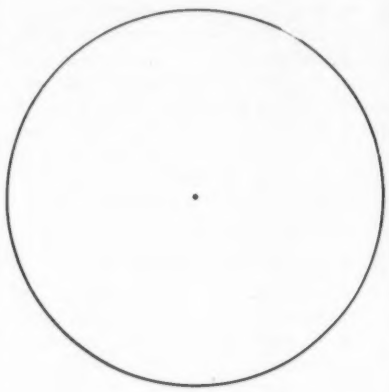

Figure 2
Dot and Circle

Historical Background

First we have in *Figure 5A,* the problem of type reproduction familiar to all as the printed words in newspapers, textbooks, magazines and all such printed matter. Type originated by carving the letter images in relief. The first record of printing goes back to the Chinese who inked the surfaces of stone tablets carved in relief. By impressing paper or the skins of animals against the raised inked characters they reproduced the images in ink.

Much later in history, the Monks of Europe printed books by carving the entire page of the book in raised characters or letters. These blocks of wood were inked in the same manner as a "page of type" would be today, and the book pages were printed by successively inking the raised surfaces of the letters and impressing sheets of paper against them in a "press."

Obviously, the hand carving of each individual letter in an entire book was a very slow and laborious task. It took a great deal of training and skill on the part of the carver, particularly since the letters have to be carved "in reverse" so that the direct impression would be "right reading." You will

[1] Printing—Testing Department, S. D. Warren Co., Cumberland Mills, Maine.

Figure 3

Black and White Halftone

note that the type plates are a "mirror image" of the final copy.

It remained for one Johannes Gutenberg, in the year 1450, to come up with a revolutionary idea in the art of type reproduction. Gutenberg conceived of the idea of carving each letter character as a unit. By carving a relatively small quantity of individual letters, he could assemble those to his liking to produce the words and paragraphs of a book page. After printing the required number of copies from this page, he could disassemble the type and rearrange it for another page. Thus came into being the art of printing from *movable* type.

Here in *Figure 6* we see Johannes himself, together with his press and crew, examining the first press sheet ever printed from *movable* type. A sample of the Bible page he is examining is also shown. Copies of this Bible are still in existence at $50,000 a copy. You can obtain a more readable copy at a lot less money at any bookstore thanks to more efficient printing methods today. The Bible has led all other books in publication volume since Gutenberg's edition. It is still *the* best seller.

It is obvious that Gutenberg's discovery allowed an enormous increase in the production of printed matter. The next big step was production of a matrix or mold from which letter characters could be cast in great volume with a minimum of hand labor. An unlimited volume of type characters available at reasonable costs gave further impetus to the printed word, and printed matter for the first time became available to the masses of people.

Hand-set movable type served until after the War between the States when newspapers and magazines began to grow with leaps and bounds. As the great metropolitan daily newspapers began to grow, a severe bottle-neck developed around the hand setting of so much type day after day.

It became obvious that some mechanical means should be devised for setting type if this industry was to continue its growth, and particularly if it was to speed up new coverage. The answer, of course, was the so-called Linotype machine and equivalent devices for mechanically setting type into words and lines. The operator simply selects the letters on a keyboard similar to a typewriter and the machine finishes the job of casting a complete line of type ready to be locked up in the printing form as shown in *Figure 5A*.

Reproducing Black and White Copy

So much for the development of the printed word up to the present time. But how about the illustrative art or picture. You have heard the expression, "A picture is worth a thousand

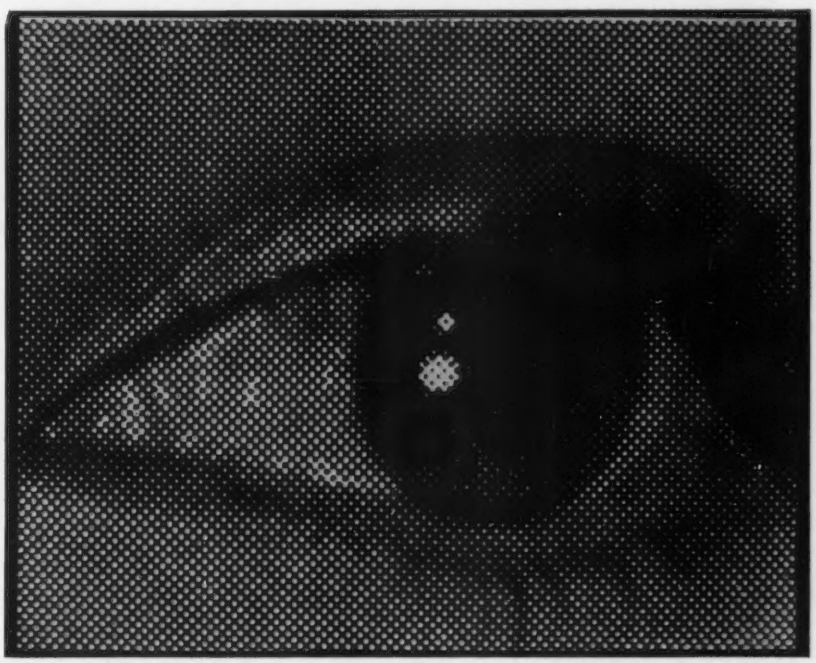

Figure 4

Enlarged Section of Halftone in Figure 3

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Demonstrating the opacity of
Demonstrating the opacity of paper through ten steps of type faces on th
Demonstrating the opacity of paper thro ugh ten steps of type faces on the various
Demonstrating the opacity of paper through ten steps of type faces on the various grades of stock
Demonstrating the opacity of paper through ten steps of type faces on the various grades of stock to determine at which point the maximum amount of ink mass will not disturb the opacity
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Figure 5A

Type sizes

Figure 5B
Line Cut

words." This is reason enough for a strong desire to reproduce illustrative art and thereby make the work of the masters available to the masses.

Line copy, such as we have in *Figure 5B* was reproducible in the same manner as type. That is, the *line* drawing could be carved or etched in wood or metal and the raised portions inked and printed. The so-called wood-cut illustration accompanied type reproduction down through the ages. There are a number of intermediate developments in the reproduction of illustrative art, but we must step quickly along the path of time and return to modern methods of reproducing tone copy by the halftone screen.

The original portrait of *Figure 3* represents typical photographic copy which we wish to produce. The tonal values that make up the detail and features of the subject are obviously varying degrees of black and white. That is, they are varying intensities of grey tones. The underlying paper background is white. Over this white background is a film of "silver emulsion." When the photographic copy paper was exposed to light under the negative image of this young lady, light passed through the "clear" areas of the negative and caused a black silver deposit to be formed. Where the negative was black no light penetrated and so only white paper is exposed to view. In other areas, the negative is only partially black and so some light gets through to form black and silver on the copy paper. But this black deposit is not heavy enough to cover the white paper pigment completely so a grey tone is formed in these areas. The "darkness" or the "whiteness" of the grey is governed by the relative intensity of the negative. Obviously, the picture is made up of an infinite variety of grey tone values ranging from jet black to pure white.

Now we wish to reproduce this photographic copy by printing methods. To do this by the relief method similar to the wood cut and type already mentioned, we will have the black areas in high relief so they will take ink and the white areas can be cut away so they will take no ink and we can print both ends of the tone scale. But what about all the intermediate grey tones? They either have to be high enough to take ink all over or low enough to miss the ink altogether. There is no means of mechanically selecting all values of the grey tones by mechanical relief. So it is impossible to reproduce these grey tones by mechanical relief. So it is impossible to reproduce these grey tone values by any variation in the degree of relief.

We do know, however, that line subject can be reproduced in black and white and we can reason that if the line subject is fine enough so that the lines cannot be detected by the eye, that the eye will integrate the effect of black and white lines into a grey value. This we can demonstrate with simple cross hatching, or, better still, if we make a disk which is half black and half white and whirl it fast enough, the black and white will mix to form a perfect middle-tone grey.

This brings us back to the so-called "halftone" method of tone reproduc-

tion of tone copy. To make this easier to explain and follow, let us use this "grey scale" of *Figure 7* representing 10 uniform steps along the infinite range of greys from black to white. This will serve to show us how the infinite variety of tones in the "continuous tone" photocopy is reproduced in line or halftone by the screen process.

This tone scale will help too, in explaining why grey values cannot be reproduced by relief printing. An ink film is black. If any step is inked it will print pure black. We cannot control the ink film "thickness" to reproduce intermediate tones so we must deceive the eye with a fine line rendition of these values.

Now, if we take this grey scale and put it in front of a camera, we can rephotograph it with precisely the same tone values. But this time we must convert it from a "continuous" tone to a line subject. This is done with a "camera screen" as shown in *Figures 8 and 9*. The camera screen breaks up the continuous tone of the grey scale into "dots" of varying size. At the near-black end of the scale tiny spots of white paper will show through the ink film to give a very dark grey tinge. Obviously, the true middle-tone grey is half black ink area and half white paper area. This middle-tone area is exemplified by the checkerboard dot pattern at the exact middle point of the scale.

Thus, the camera and camera halftone screen combination can convert a so-called continuous tone copy into a *line* or dot pattern copy so that all intermediate grey tones can be reproduced by relief printing. With these *Figures 7 and 8* before us we can see how the camera "looks" at a given area of the original continuous tone copy and with the aid of the halftone screen "decides" how large the screen dot shall be to accurately reproduce that area in black ink on white paper.

Reproducing Color Copy

So much for the reproduction of pictures in mono-chrome (one color, or black and white). But what about the reproduction of our final piece of copy of *Figure 10* the poly-chrome painting? We certainly want to be able to reproduce with ink and paper every detail and color shading in fine oil and water-color paintings. So let us take this color copy back to the camera, as in *Figure 9*.

Coming back to the camera, it may be of interest to mention that the copy can be enlarged or reduced. You will note that the camera "bellows" allows the lens to be moved back and forth between the film and copy board. At a given position of the lens, copy is "same size." As the lens moves forward toward the copy board the picture focused on the film grows larger. Conversely as the lens moves back from the copy the picture grows smaller on the film. Thus, we are able to fit the size of copy to our convenience in the final printed layout, and are not confined to the original copy size.

Now the job of reproducing the color copy: If we put the original copy on the camera copy board and photograph it through the camera screen in the same manner as we did with the black and white photo copy, we can get rendition of the color copy that can be printed in black ink and which will give us the recognizable detail of

Figure 6
The First Impression from Movable Type

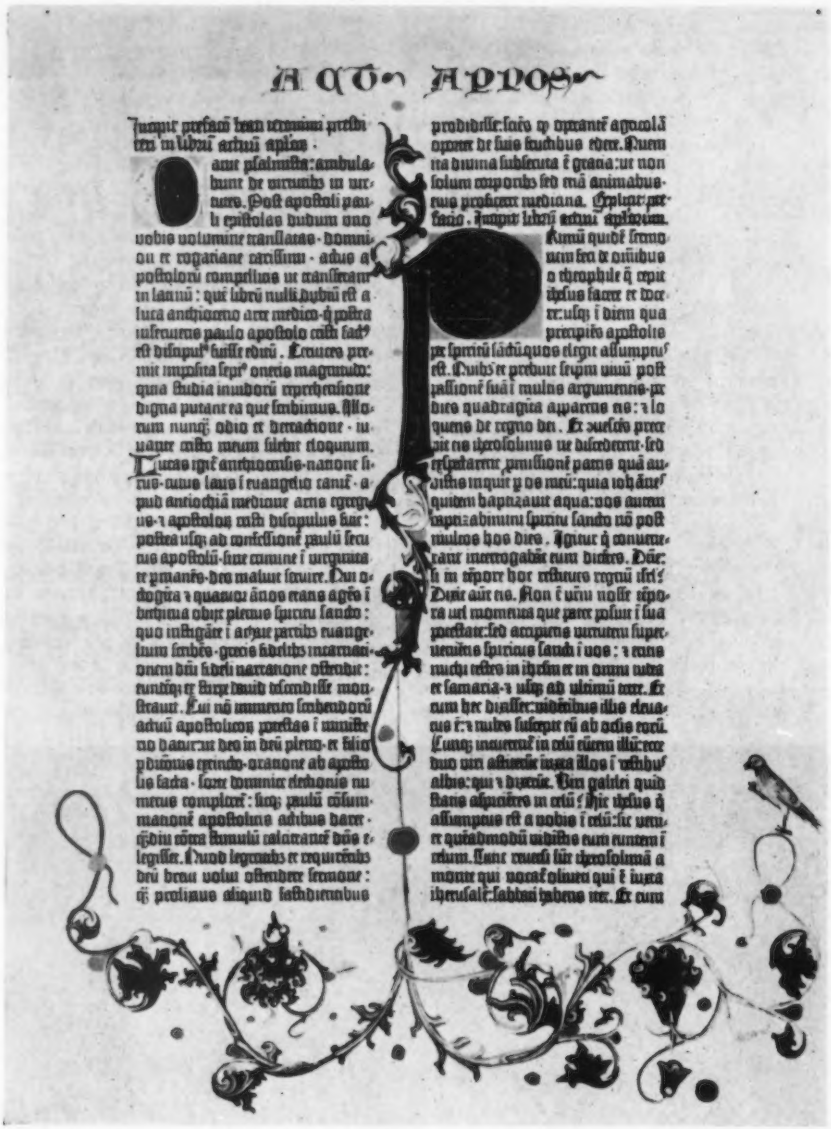


Figure 6A

This is a black and white reproduction of a page from the original Gutenburg Bible. The embellishment was added by hand after the text was printed. It is done in color.

the picture. This would be no different than a black and white snapshot picture of a colorful landscape scene. But if we wish to reproduce the picture in its exact color tones we obviously must use colored inks.

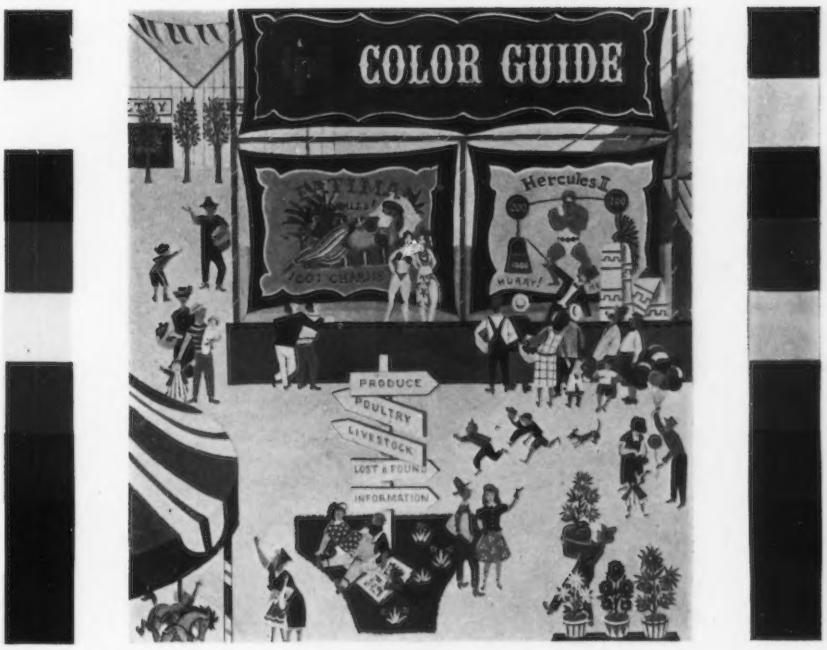
The artist, in painting this picture, used a great many colors and tints, arbitrarily chosen, mixed and overlaid to achieve the color effects he desired. To print the picture in colored inks we first must "separate" the colors on the copy. Fortunately, we do not have to separate the colors into the precise colors the artist used, because as you will recall from your physics course all colors of the rainbow can be made from three primary colors: namely, yellow, blue and magenta (red). So that is how we are going to separate the colors of this painting. We are going to break down all of the various colors into the three primary colors and "repaint" the picture in the three primary colors, using printing inks. *Figure 10* shows the steps used in the color separation.

We first place a red filter in front of the camera lens. The camera is now viewing the color copy through "rose colored glasses." A red filter removes all of the red light reflected from the copy and also all the yellow light. The only light that can now reach the film is the primary color *blue*. This blue light forms dots through the halftone screen and onto the photographic film in the back of the camera. The dot areas corresponding to various parts of the picture will be controlled in size according to the intensity of *blue* in that particular part of the picture. Thus we *separate* all of the blue from the color copy and record its intensity by varying dot size on the film. This gives us what is called the blue printer or blue printing plate. If we print this blue plate using blue ink we will have all the various shades of blue that the painter put into the copy, plus all the blue he may have mixed with other colors to make different shades.

Next we take another camera shot of the copy through a *green* filter to get a *red* printer. And finally a shot through a *blue* filter to obtain the *yellow* printer. We now have the colors of the copy separated into the three primaries which can be recombined in printing to form an accurate reproduction in ink.

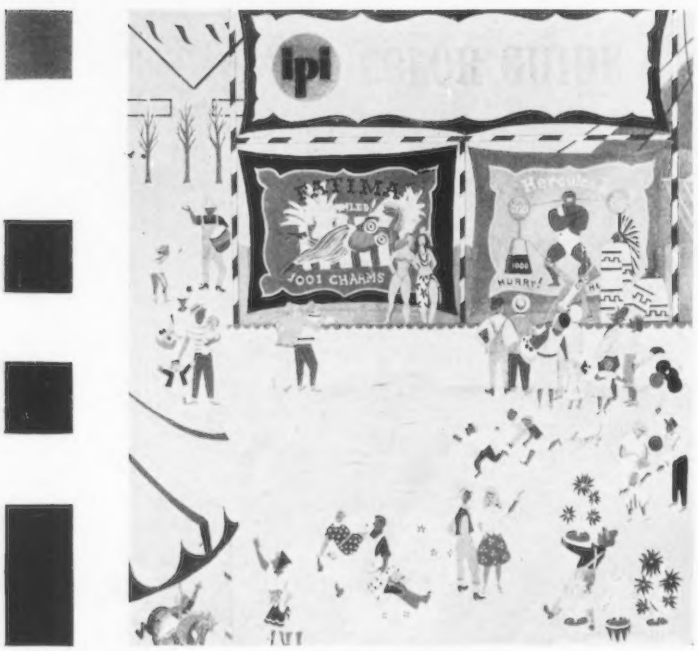
Now I must anticipate the question as to why this "Progressive" of *Figure 10* shows that four press colors or

YELLOW

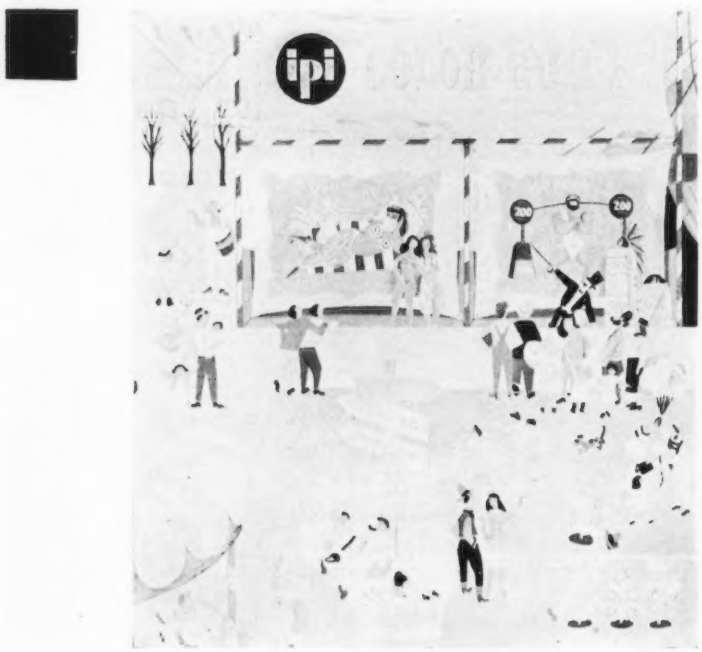


THREE-COLOR

Figure 10—An Illustration of Electronic Color Correction and a set of 4 color separations

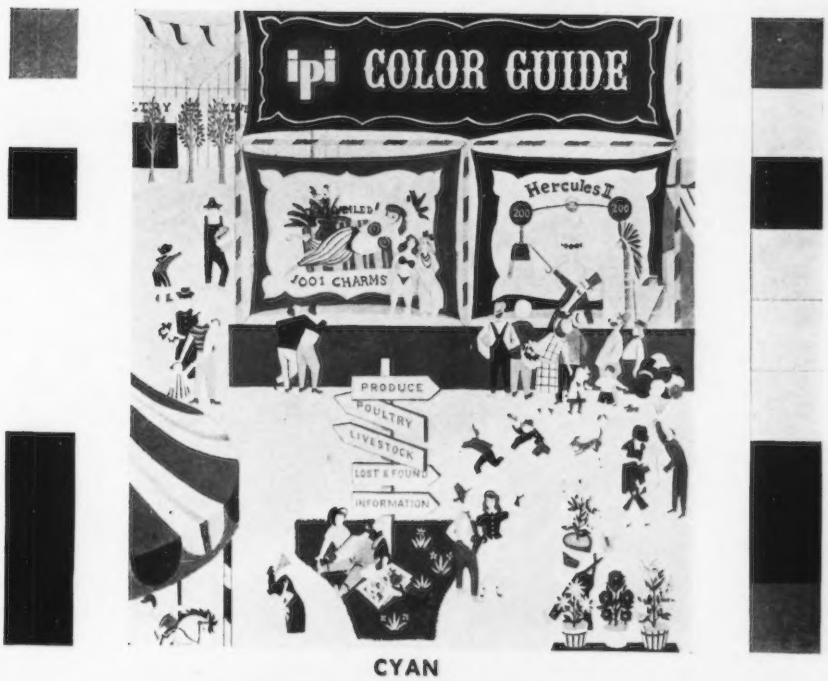


MAGENTA

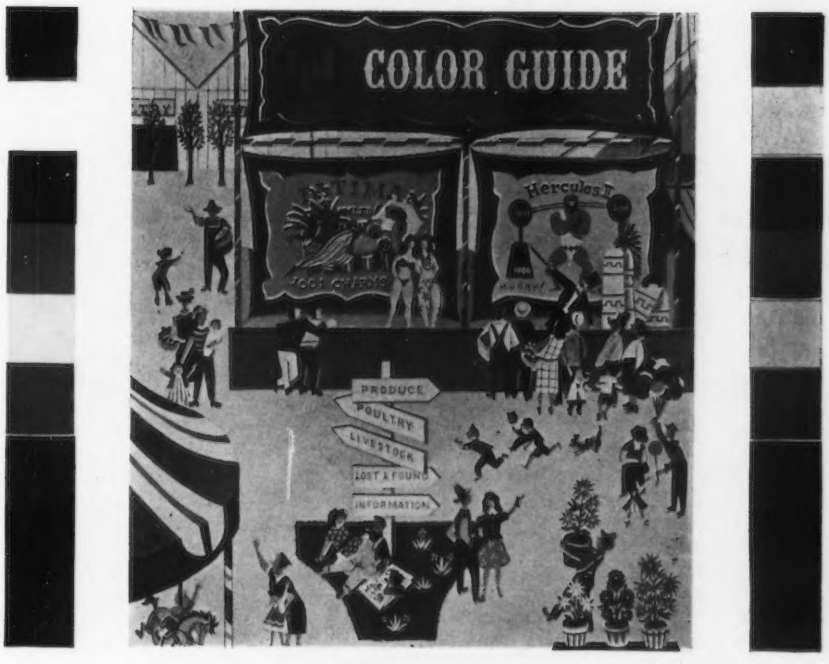


BLACK

The plates used to print the illustrations on these four pages were prepared from electronically color-corrected separation images. No handwork was performed at any stage, and the



CYAN



FOUR-COLOR

fidelity of reproduction may be judged by comparing the original color chart which appears on the left of each plate with its reproduction on the right.

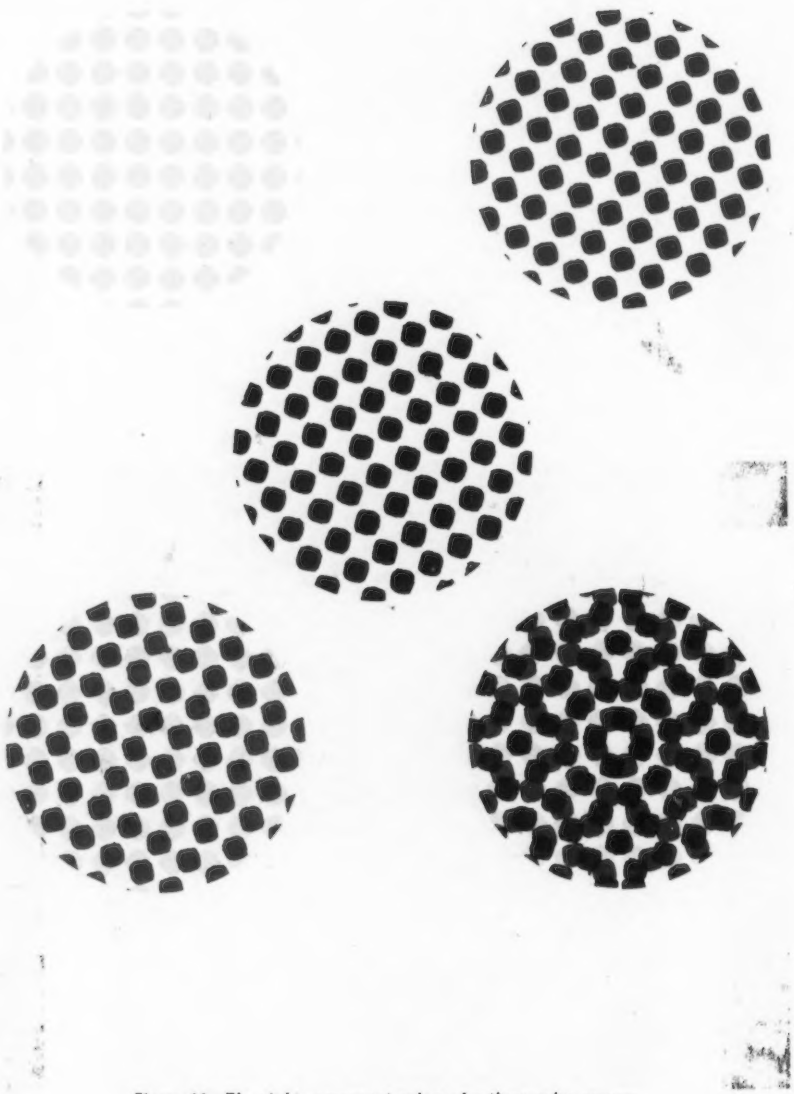


Figure 11—The eight component colors of a three-color process.

The color plates used in this article, were supplied by the courtesy of the Interchemical Corporation. These plates were prepared from electronically color corrected separation images. No hand work was performed at any stage.

plates were used to reproduce the picture whereas we have explained that only the three primary colors are necessary. Technically I am still right because this fourth "color" is *black* and black is not a "color" as you know, but rather the absence of color! We haven't the time to explain the complete story behind the "black printer" in four color process printing, so let us sum up the problem this way:

Evidence that reproduction can be done in the three primary colors can be seen in all photographic color reproduction such as photographic color transparencies (Kodachrome) and dye transfers (Kodak washoff relief) where only the three primary colors are used. But printed reproduction imposes several limitations. First, we have to break the picture up into screen dots so we lose some detail. Second, the color separations achieved with the camera filters are not a perfect match for the ink colors and so we lose detail and color values. Third, we must use transparent inks so that one color can "show through" another to make all of the color combinations, and these transparent inks lack the ability to produce strong dense black values that give the picture punch, sparkle and detail.

So, a black printer is made by "faking" with a lot of tricky camera and art techniques to make a black printer that will cover up some of these shortcomings in the ink reproductions of color copy.

Now to leave the camera and get back to our dot reproduction story again. Let us refer again to *Figure 4.* Here it is apparent how black and white tone control is achieved by the variable dot size. This same variation in dot structure controls the *depth* of any one color in a color printing plate. This is obvious when we note the variation in depth of a given color on the *progressives* in *Figure 10.*

Now if we enlarge a section of the final printed reproduction in *Figure 11* we see a random intermingling of the color dots the effect of which when mixed together will give a color sensation to the eye equivalent to some particular section of our original picture.

Now that we have created these dot structures photographically, we must convert them into a physical printing surface that will carry ink to paper in precisely the right amount and put it in precisely the right place on the paper surface.

The Three Major Printing Processes

As we stated previously, there are three major methods of putting ink on paper, namely, letterpress, lithography and gravure.

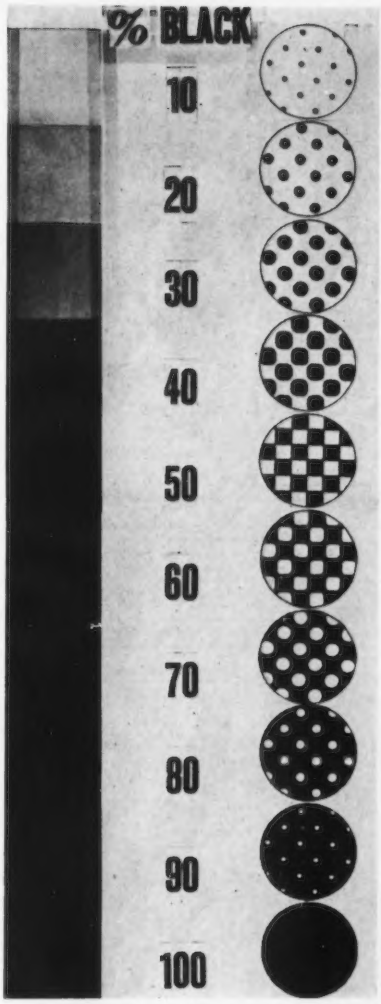


Figure 7
Tone and Dot Scales

The thing that distinguishes one printing process from another is, of course, the nature of the printing plate itself. So we will go through the basic steps of making a printing plate for each of the three major printing processes. As copy let us select the simple convention of the grey scale from the camera drawing, *Figure 9,* so we can more easily visualize how the varying dot size is physically produced on the plate surface.

The top section of this drawing *(Figure 12A)* represents the "screened" photographic film camera negative carrying the halftone dots of varying size according to the grey intensities of the various steps of the grey scale.

The second section *(Figure 12B)* represents a copper "plate" coated with a thin layer of colloid (in this case fish glue) which has been made "sensitive" to light by the incorporation of ammonium bichromate. When light of high intensity in the blue-violet range shines on this sensitized colloid coating it causes the coating to insolubilize or harden.

Now if we lay the photographic halftone upon the surface of the light sensitive colloid over the copper and place this sandwich before a strong arc lamp, the light will shine through the clear film *between* the dots and insolubilize the colloid coating in these areas.

After exposure, if we wash this plate surface with water the soluble coating under the dots that was protected from light, will wash away leaving the copper plate beneath exposed. The plate with the remaining hardened glue "Stencil" is next placed in an etching bath (ferric chloride). Where the metal is bare the acid will dissolve it away, and where it is protected it will remain undissolved. The next section of the figure *(Figure 12C)* represents the finished letterpress engraving with the protective coating or stencil still in place on the raised portions.

The next group of figures *(Figure 13* represent the same camera halftone negative placed for exposure to a lithographic plate. The lithographic plate metal is a relatively thin sheet of zinc or aluminum with a grain or tooth on the working surface. This grained surface is also coated with a light sensitive colloid. (Egg albumin-ammonium bichromate.) Here again the light exposure is made to harden the colloid film that is exposed to light between the dots on the film. After exposure the colloid layer is covered with a greasy (hydrophobic) film of ink). The plate is then immersed in water and the soluble parts of the colloid washed away, leaving the hardened colloid "dots" or printing image attached to the plate and covered with the greasy ink film. Instead of etching this image into relief, the metal is

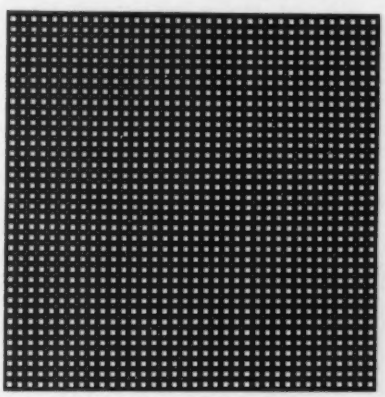


Figure 8
Representation of Halftone screen

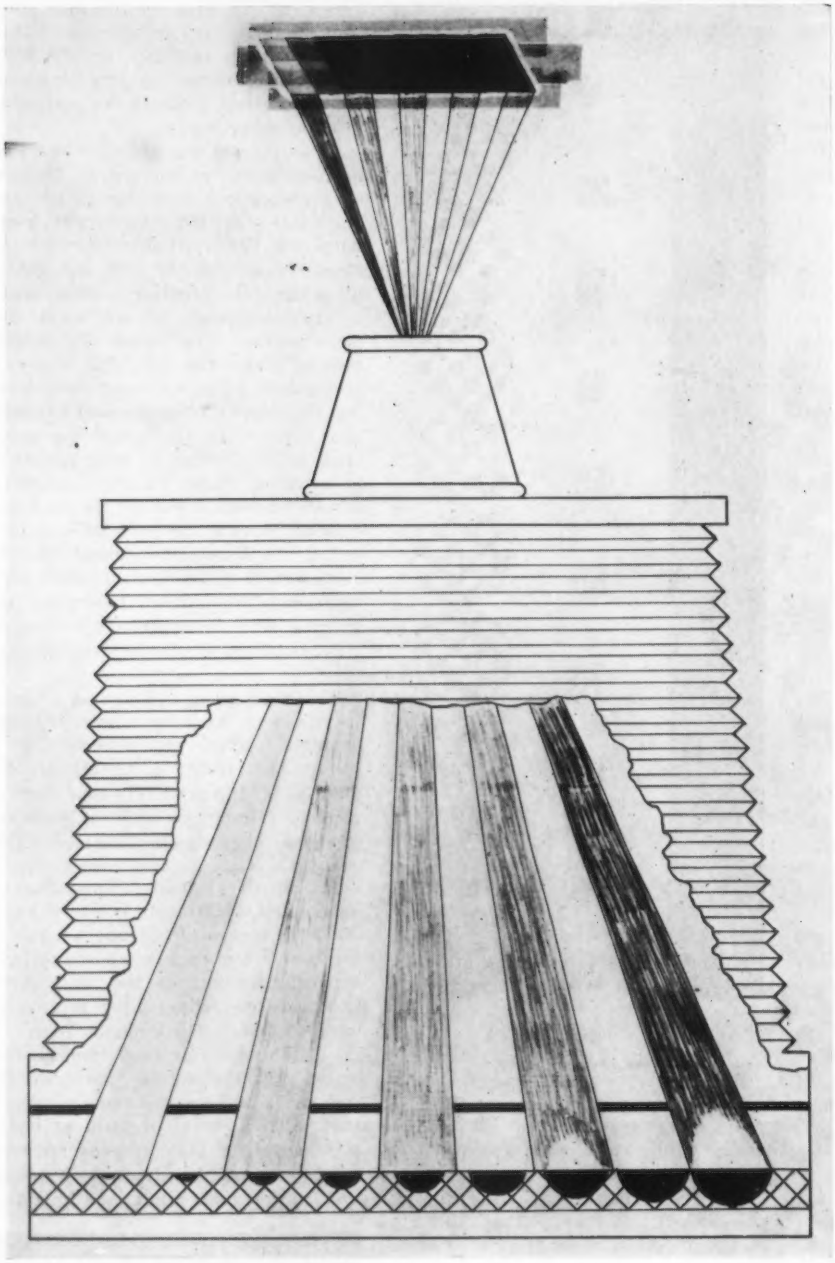


Figure 9
Schematic Representation of Halftone Camera

treated with a water absorbing (hydrophilic) colloid.

This lithographic printing surface does not depend upon relief of the printing surface to differentiate between the printing and non-printing areas of the plate, but rather operates from a plane surface on the principle that grease (or hydrophobic substances) do not mix with water (or hydrophilic substances).

Figure 14A shows the letterpress and *Figure 14B* the lithographic plate as they appear ready for printing our "grey-scale" image with a black ink. The letterpress engraving carries the ink on the high relief dots. The lithographic surface can best be visualized from the actual plate sample, but this illustration shows the black ink film on the printing areas and the *water* film in the non-printing areas. Here the water film prevents ink from "taking" in these areas.

So far we have said nothing about the gravure printing plate. *(Figure 14C)*. The photographic preparation is quite complex, so I have avoided this detail in order to prevent too much confusion. For our purpose it should suffice to point out the *two* outstanding difference between a letterpress engraving and the gravure plate (or cylinder) printing surface.

You will note first that the black ink is down in the etched holes or "wells" of the plate surface rather than riding up on the peaks as in the letterpress engraving. Second, you will note that halftone dots are all the same width or diameter in this cross-section view of the grey-scale image, but that the dots vary in depth. Thus, it is apparent that tone values in gravure printing

Top to Bottom Figure 12A-12B-12C

Halftone Negative

Sensitized Plate-Exposed

Finished Letterpress Engraving

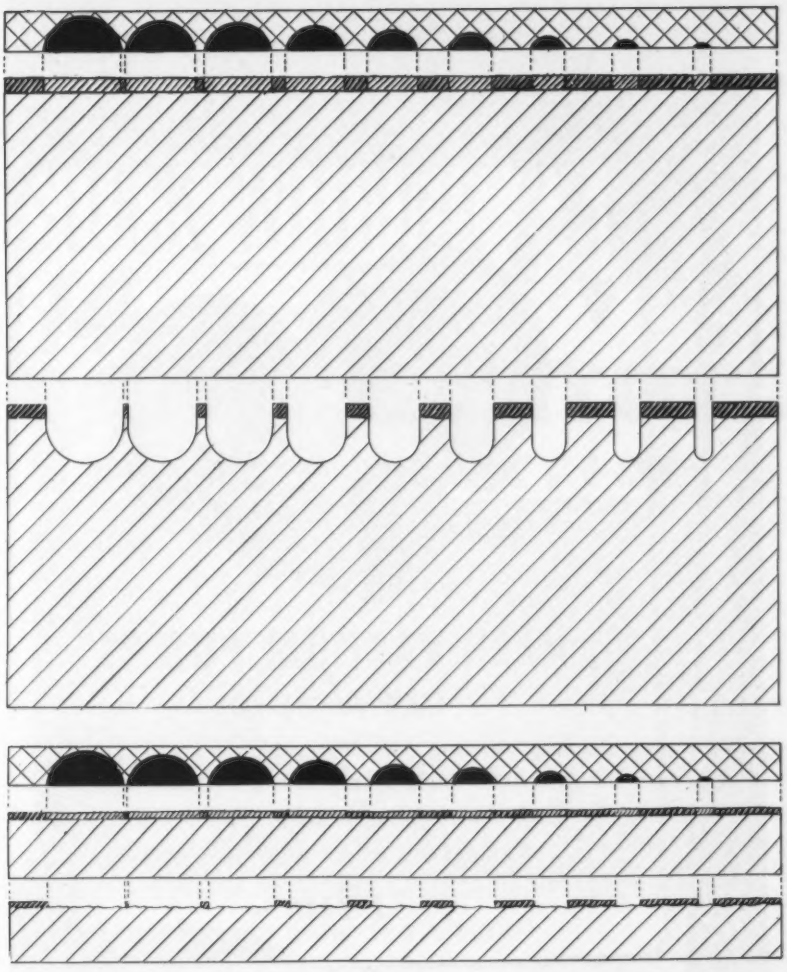


Figure 13

Steps in preparation of Lithographic Plate

Figure 14A

Letterpress Plate

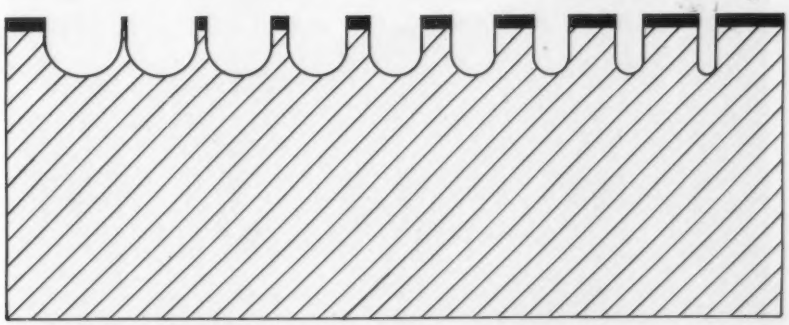


Figure 14B

Lithographic Plate

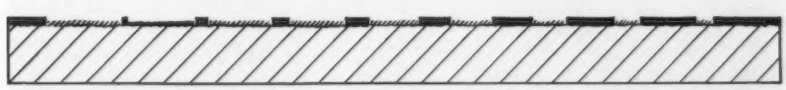
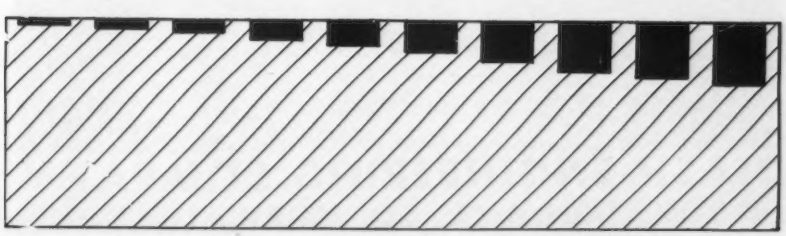


Figure 14C

Gravure Plate



10
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are achieved by the amount of ink put on the paper for each color value rather than by variation in dot size. In other words, color intensity is varied by depth of the "ink wells" rather than by their relative areas.

The mechanism for inkng the plates after each printing impression are obvious from these drawings. Letterpress and lithographic plates can be inked with a semi-plastic ink mass by rolling an ink charged roller over the surface of the plate and allowing the roller's ink film to split the printing surfaces of the plate.

Gravure ink, on the other hand, must be a very fluid substance that will allow it to flow into and out of the ink wells at high speed. Ink rollers are not used to ink a gravure surface, but rather the whole plate surface is flooded with the fluid ink, and then the excess is removed by using a straight-edge, squeeze, or "doctor-blade" as it is most commonly called, to remove the excess ink. The doctor blade bears on the high, non-printing areas and scrapes them free of ink, leaving the etched well of ink to be drawn out as it contacts the absorbent surface of paper.

Conclusion

With these means of reproducing tone subjects, we can carry these same basic principles to line and type copy for each of the three printing processes. The problem now resolves itself into one of designing suitable press equipment which will carry these printing plate surfaces to best advantage.

Results of Army Timber Sales

WASHINGTON, D. C. — Army timber sales from military-controlled areas in southeastern states in the past four years have come to more than four million dollars, according to a summary of these activities recently issued.

Sales included timber, pulpwood, and salvaged lumber, from 867,218 acres, and totaled the equivalent of 175,572,237 board feet, exclusive of 120,000 cords of pulpwood.

Projected further cutting from such lands in the next eight years, it is said, will yield nearly five million dollars annually, and by 1980, through continued management of forest resources in military areas, may reach eight million dollars annually. Against these returns, Army is said to be spending $400,000 annually for labor, fire protection and administration, supplies, etc.

Canadian Exports Drop

Canadian exports of wood pulp declined to $189,741,000 during the first seven months of this year compared with $197,646,000 in the corresponding period of last year, Canadian Government reports, adding, however, that exports in this period of newsprint advanced to $332,569,000 against $299,846,000 a year ago and exports of other paper increased to $21,558,000 compared with $20,755,000 in the same period of last year.

Exports of wood pulp during July declined to $18,088,000 compared with $34,286,000 a year ago and exports of newsprint dropped to $48,744,000 against $51,344,000 last year. Exports of other paper amounted to only $1,866,000 during July against $3,329,000 a year ago in same period.

A.P.W.

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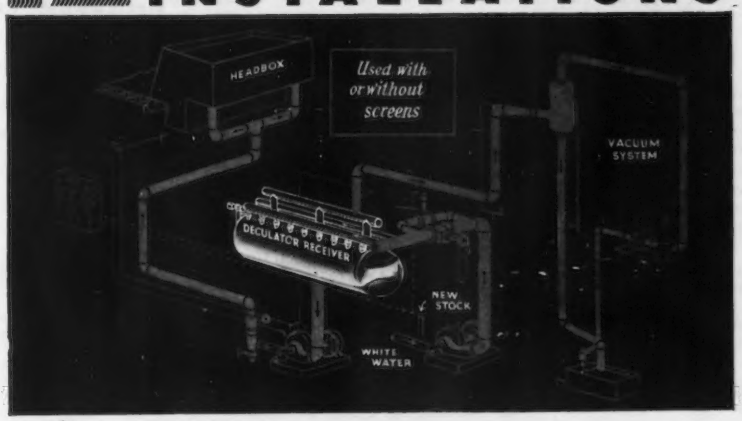

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for the addition of moisture and chemicals
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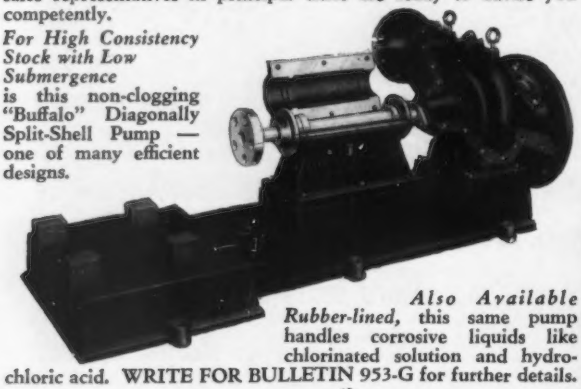
How To Select The Right Pump

First, determine all expected conditions—nature of liquid to be pumped, consistency, temperature—discharge pressure—maximum and operating capacities—suction lift or suction head. "Buffalo" builds a complete line of stock pumps to meet all stock conditions. By making the best possible choice, you conserve strategic materials, save money and get complete satisfaction. "Buffalo" sales representatives in principal cities are ready to advise you competently.

For High Consistency Stock with Low Submergence is this non-clogging "Buffalo" Diagonally Split-Shell Pump — one of many efficient designs.



Also Available *Rubber-lined,* this same pump handles corrosive liquids like chlorinated solution and hydrochloric acid. WRITE FOR BULLETIN 953-G for further details.

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34 leading pulp and paper companies have recently placed repeat orders for Blaw-Knox Pulpwood Grapples. Bulletin 2302 tells why—actual on-the-job illustrations show how others are cutting rehandling costs. *Send for your copy of Bulletin 2302 today!*

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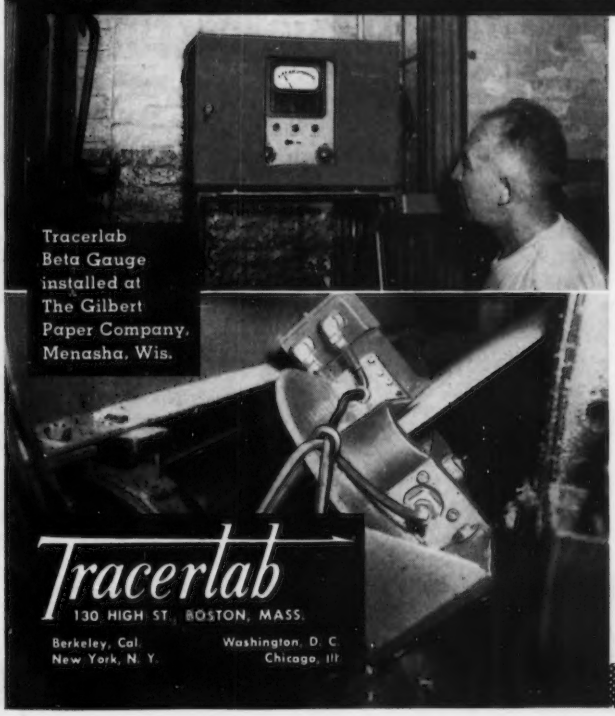
BRANCHES: BOSTON HOLYOKE PHILADELPHIA KALAMAZOO CHICAGO

Production Men Like Tracerlab BETA GAUGES Because...



Tracerlab Beta Gauge installed at The Gilbert Paper Company, Menasha, Wis.

Every production man is interested in cutting costs and improving product quality. If you can do both at the same time you've got an unbeatable combination to fight today's competitive battle. Manufacturers who have installed Tracerlab Beta Gauges for sheet process control are reaping both these benefits. Here's what two out of many say:

$ **"Ability of Tracerlab Beta Gauges to hold product thickness variation to ±.002" instead of ±.004", as formerly, enables operators to work more closely to minimum specifications, thus making possible savings of over $150,000 yearly." (Two Tracerlab Beta Gauges in use, two on order.)**

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Long-life Suction Box Cover reduces operation costs . . . is stronger . . . eliminates sagging and breakage

A selection of segments is offered to progressively dry and form the sheet to suit your particular water removal problem.

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Greater open area in this end grain hard maple construction.

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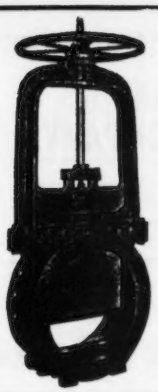
THE LO-VAC SUCTION BOX COVER IS TIME-TESTED *and* PROVEN FOR INCREASED PRODUCTION AT LOWER COST PER TON.

Lo-Vac provides far greater open area and is capable of removing more water at a lower vacuum resulting in longer wire life. We recommend this cover in positions on the machine where greater water removal is required.

APPLETON WOOD PRODUCTS CO. APPLETON · WISCONSIN



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METALS — I.B.B.M., all iron, bronze or stainless steels, body parts plain or rubber lined.

The photo of 24" Fig. 241 I. B. B. M. valve wnue illustrating the gate bottom wedge system for forced gate seating and "GUILLOTINE" edge for shearing fibre at seat also shows the packing box and yoke as separate units. Both adjustable.

- The "FAST THREADED" screw stem and ball bearing speeds valve operation.
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is impossible with old, worn Screen Plates. Change to new, fine-cut "Fitchburg" Screen Plates and be amazed at the instant improvement in QUALITY.

"FITCHBURG" *New Type—Duplex Slot*
FLAT PLATES
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Single Instrument Measures Smoothness, Porosity and Softness of Paper

You just interchange the lower test plates in the GURLEY-HILL S-P-S Tester to convert it into an instrument for testing either smoothness, porosity or softness of any type of paper, by measuring a given air-leakage over or through the paper.

This 3 in 1 laboratory "assistant" is simple to operate, quick and accurate, and a real utility instrument where printing quality of paper must be reliably measured.

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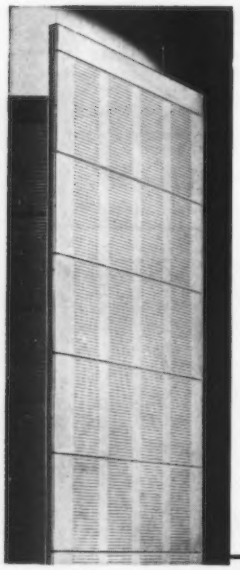
for High Plate Capacity — Long Plate Life



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Metalworkers for the Paper Trade

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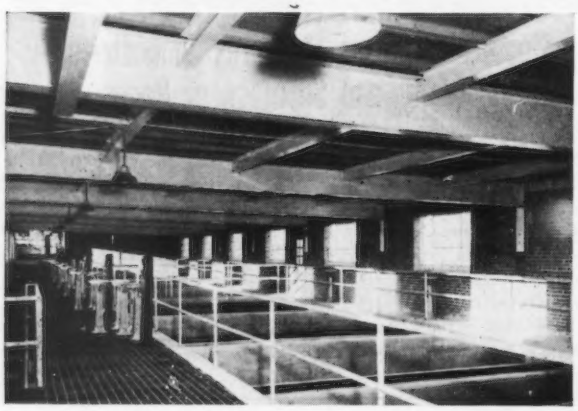
VALVES: GATE, SWING CHECK, BLOW, GLOBE, ANGLE AND "Y"



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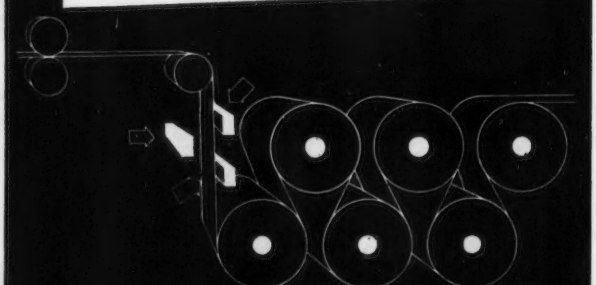
Controls and safeguards are furnished as required by the specific installation.

Further information concerning your particular drying requirements will be furnished by us without obligation. We invite your inquiry.



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MEN WANTED — POSITIONS OPEN

We can place—Supts., night supts. and asst. supts. for Cylinder and Fourdrinier mach. paper mills; Manager gumming plant; mgrs., supts., Foremen and mechanics for converting plants; mgr. bag mfg.; day supts., night supts. and asst. supts. board mills; supt. for asbestos cement shingles, flat sheets and corrugated board; board mill coating supervisor; asst. treas. and general accountant for southern paper mill.

Chemists, chem. engineers and laboratory men; purchasing agents and asst. purch. agents; pulp and paper technologists; plant engineers, asst. plant engineers, mech. engineers, master mechanics, maintenance and mach. shop foremen, designers and draftsmen, salary range $5,000 to $10,000; Cylinder and Fourdrinier mach. foremen; power supervisors; salesmen to sell fine papers, newsprint and board, also salesmen and demonstrators to handle chemicals and other materials for pulp and paper mills and paper converting plants; beater engineers; mach. tenders and back tenders.

LIST YOUR CONFIDENTIAL APPLICATION WITH US to keep informed of attractive positions open in the pulp and paper mills.

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N-14

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Experienced Accountant to act as comptroller and office manager in small paper mill. Must be able to install cost accountnig system, new office routines and forms to facilitate work and assemble necessary information. Reply giving resume of experience, references, full personal data to Box 52-474 c/o Paper Trade Journal. N-21

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For Paper Mill Manufacturing High Grade Folding Boxboard. Splendid Opportunity with Progressive Firm for Man of Proper Qualifications. Reply to Box 52-453, c/o Paper Trade Journal. TF

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Under general direction of comptroller, to supervise general accounting dept., maintain general ledger, develop financial statements, prepare all tax returns, and handle operating budgets. Should have college degree plus at least five years of accounting experience in paper industry. In reply summarize training and experience. Address—Bowaters Southern Paper Corporation, Calhoun, McMinn County, Tennessee. TF

PLANT ENGINEER

To coordinate activities of design engineering firm and contractors during construction. Direct all engineering and maintenance in completed mill. Should have not less than ten years experience in pulp and paper mill maintenance. Experience in maintenance of sulphate pulp production facilities necessary. Familiarity with groundwood and newsprint production desirable. Summarize experience. Bowaters Southern Paper Corp., Calhoun, McMinn County, Tennessee. TF

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SALARIED POSITIONS $3,500 to $35,000. We offer the original personal employment service (established 42 years). Procedure of highest ethical standards is individualized to your personal requirements. Identity covered; present position protected. Ask for particulars. R. W. BIXBY, INC. —117 Dun Bldg., Buffalo, 2, N. Y. N-14

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WANTED—Young Industrial Engineer with experience in paper manufacturing and finishing for paper manufacturing and converting mill in New York State. Please state all particulars and salary requirement in first letter. Address Box 52-479 care Paper Trade Journal. N-21

WANTED—Chemist for rag mill located in New England. Address Box 52-478 care Paper Trade Journal. N-14

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WANTED—Position as Chief Engineer. 20 years experience in Steam Power Plants and heat balance work. Age 46, married. Have first class engineer's license and best of references. Address Box 52-424 care Paper Trade Journal. N-14

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EXPORT ASSISTANT or Manager, specializing paper. Thoroughly experienced all phases, documents, L/C, English-Spanish Correspondent Stenographer. Accounting. Address Box 52-475 care Paper Trade Journal. N-28

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1—Dilts Continuous Breaker Beater, bandless roll 74″ dia. 72″ face, all steel construction, hollow midfeather, tub 50 ft. long 15 ft. wide, automatic rag catcher. Excellent condition.

2—Dilts Continuous Liner Breaker Beaters rolls 72″ dia., 60″ face, keyed bandless type, cast iron tubs 35 ft. long, 9 ft. 10 in. wide. Each with electrically operated rag catchers. Very good.

4—Dilts 2000# Cast Iron tub rebuilt Beaters in good working condition (at your own price).

3—14 Plate Shartle Flat Screens with plates for cleaning and settling system. Rakers full length operated from one drive.

1—Steel Settling Trough. Two 70 ft. channels 42″ wide 30″ deep with baffles and cleanouts.

1—8x16″ Downingtown Triplex Stock Pump.

2—6x12″ Downingtown Triplex Stock Pumps.

2—2-A Bird Rotary Screens, copper vats.

4—12 Plate Sandy Hill Flat Screens with roller shoes.

1—8 Plate Sandy Hill Flat Screens with roller shoes.

4—12 Plate Sandy Hill Flat Screens, standard toe block.

3—8x6 Sandy Hill Open Impeller Fan Pumps.

1—2700 G.P.M. 102 ft. head Frederick Stock Pump.

2—1000 G.P.M. 50 ft. head Frederick Stock Pumps.

1—No. 1 Nash Hytor Vacuum Pump.

1—25″ dia. 155″ face Rubber Covered Suction Press Roll.

1—14½ Dia. 70″ face Suction Couch or Drum Roll.

1—14¼″ Dia. 88″ face Suction Couch or Drum Roll.

1—R. C. Couch Roll 24½″ dia. 140″ face, New Rubber.

3—R. C. Couch Rolls 12″ dia., 72″ face, New rubber.

1—Pair Smoothing Rolls 18″ dia., 120″ face brass covered, anti-friction bearings & stands, used very little.

1—Shartle Decker, cylinder 36″x120″, steel vat.

1—120″ Black & Clawson 2-spool Upright Board Machine Reel, will make 60″ rolls.

1—28″ dia. 148″ face R. C. Press Roll, 1″ New Rubber.

2—Beloit Enclosed Hypoid Gear Angle Drives 100 H.P. each.

1—Downingtown Enclosed Angle Drive 26 H.P. ratio 5.06 to 1.

6—New Felt Stretches with 1 7/16″ Brass Screws, Acme thread, 48″ and 60″ long, plain or anti-friction bearings.

8—Pr. New Spring Roll Brackets & Bearings 4-spring type.

2—New Air Hoists "Hannifin" 4½ bore, 94″ stroke, Model J.C. 2 N.L. double acting heavy duty.

The above is only a sample of part of our inventory and we would appreciate your inquiries for small items or complete machines. Our shop can make nearly anything you need in a paper mill.

"Every pound of paper is made on used equipment."

OSBORNE PAPER MILL EQUIPMENT CORP.

FULTON, NEW YORK Tel. 2-4254

N-14

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COMPLETELY FACTORY RECONDITIONED AND READY FOR DELIVERY

One (1) **500 KW 80% 625 KVA General Electric Alternating Current Generator,** type ATB, Form HL, 3 phase, 60 cycle, 3600 RPM direct connected to:

One (1) **500 KW Murray Condensing Turbine,** 9 stage, 240# Steam Pressure, 0-100 deg-superheat, 3600 RPM, 900 Sq. Ft. Westinghouse Surface Condenser.

Address Box 52-457, c/o Paper Trade Journal for further information.

N-21

FOR SALE: MACHINERY

1	118″ Slitter & Rewinder—Cameron type	$8,500.00
2	106″ Moore & White Sheeter with layboy	$7,500.00
1	54″ Cameron Shear Cut Slitter Type 9	$4,000.00
1	40″ Kidder Slitter—30 knives	$2,250.00
1	36″ Beck Sheeter with Electric Eye	$3,500.00
1	54″ Beck Sheeter—3 roll backstand	$3,500.00
1	Amsco Semi-Automatic ream sealing machine	$5,000.00
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Model 44W, Camachine with a 32" roll width. It has one wind shaft with a synchronizing attachment, and a "v" belt drive. The rewind capacity is 36" and the machine will attain speeds up to 1000 feet per minute. The rewind drums are 6¼ and the machine is equipped with an automatic counterweighting system. Address Box 52-472 care Paper Trade Journal.

N-14

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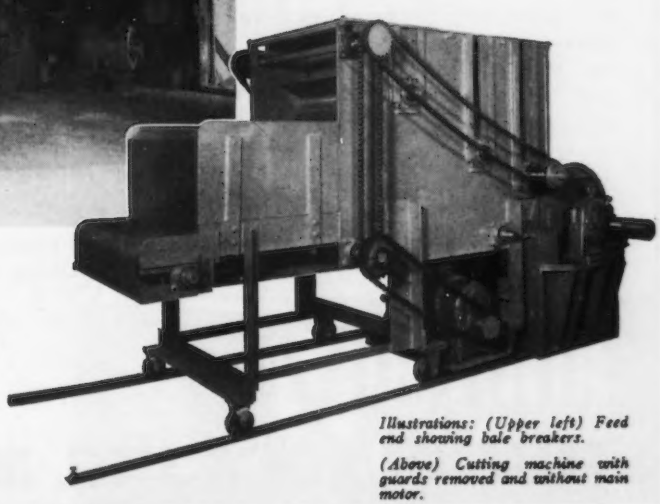

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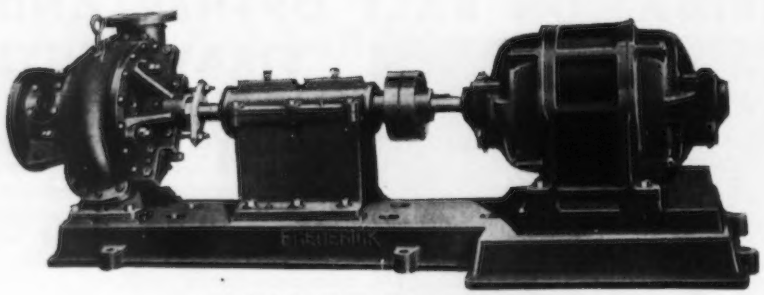
Improved Paper Machinery Corp.
Manchester Machine Co.



FREDERICK TYPE "TS" STOCK PUMP

LONG LIFE IN SERVICE

BECAUSE:

1. Adjustable casing liners both sides of impeller to protect casing and to maintain proper clearance. Adjustment made from the exterior of casing without dismantling the pump.
2. Rugged bearings—long sleeve type steady bearing to support impeller and two heavy duty double row ball bearings to take thrust in either direction, all mounted in one housing.
3. Velocities are kept low by large impeller eye. Expeller vanes provided on rear side of the impeller.
4. Pump can be dismantled without removing either the suction or discharge pipe. A diagonally split casing makes this advantage possible.
5. Designed especially for hard usage when handling high consistency stock.
6. A TRUE paper mill pump for paper mill service.

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Black Clawson Company
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Hermann Mfg. Co.
E. D. Jones & Sons Co.
Dodge Mfg. Corp.
Moore & White Co.
The Noble & Wood Machine Co.
Rice Barton Corporation
The Sandy Hill Iron & Brass Works
Shartle Brothers Machine Co.
Valley Iron Works
Waldron Corp., John

CRANES
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Whiting Corp.

CURL TESTER
Thwing-Albert Instrument Co.

CUTTERS
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Beloit Iron Works
Black Clawson Company
Dilts Machine Works
Dusenbery Co., Inc.
Gibbs-Brower Company, Inc.
Graphic Arts International Corp.
Thomas W. Hall Co.
Jagenberg-Werke Akt. Ges.
Moore & White Co.
Perkins & Son, Inc., B. F.
Rice Barton Corporation
The Sandy Hill Iron & Brass Works
The Smith & Winchester Mfg Co.
Taylor, Stiles & Co.

CYLINDER MOULDS
Black-Clawson Co.
Hayden Wire Works Inc.
Improved Paper Machinery Corp.
Manchester Machine Co.
Rice Barton Corporation
Sinclair Company

CYLINDERS
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M. W. Jenkins Sons, Inc.

CYLINDER WIRES
Hayden Wire Works Inc.
Wisconsin Wire Works

DAMPENERS
Perkins & Son, Inc., B. F.
Valley Iron Works Co.

DANDY ROLLS
Plank Company

DECKLE WEBBING
Williams-Gray Co.

DEFIBRATORS
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DEFOAMERS
American Cyanamid Co., Ind. Chem. Div.
Hercules Powder Co., Inc.

DE-INKING
Bird Machine Co.
Denver Equipment Co.
Dilts Machine Works
General Dyestuff Corp.
Kinsley Chemical Co.
Rice Barton Research Corp.
The Sandy Hill Iron & Brass Works
Shartle Brothers Machine Co.

DEINKING CHEMICALS
E. I. du Pont de Nemours & Co., Inc.
General Dyestuff Corp.
Jackson & Church Co.
Kinsley Chemical Co.
Nopco Chemical Co.

DE-MINERALIZING EQUIPMENT
Hungerford & Terry, Inc.

DEMULSIFIERS
Wyandotte Chemicals Corp., Michigan Alkali Div.

DENSOMETERS
W. & L. E. Gurley

DESIGN CONSTRUCTION
Ebasco Services

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American Cyanamid Company Industrial Chemicals Division
Calgon, Inc.
Diamond Alkali Co.
General Dyestuff Corp.
Monsanto Chemical Company
Nopco Chemical Co.
Rohm & Haas Co.
Wyandotte Chemicals Corp., Michigan Alkali Div.

DEWAXING CHEMICALS
American Cyanamid Company Industrial Chemicals Division
General Dyestuff Corp.
Nopco Chemical Co.

DIFFERENTIAL SCALES
Thwing-Albert Instrument Co.

DIGESTER CIRCULATING SYSTEMS
Fibre Making Processes, Inc.

DIGESTERS
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Biggs Boiler Works Co.
Blaw Knox Company
Chicago Bridge & Iron Co.
Combustion Engineering-Superheater, Inc.
Lukenweld
Pandia, Inc.
Paper & Industrial Appliances
Pusey & Jones Corp.

DISPERSING AGENTS
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Diamond Alkali Co.
General Dyestuff Corp.
Monsanto Chemical Company
National Aluminate Corp.
Nopco Chemical Co.
Rohm & Haas Co.
Wyandotte Chemicals Corp., Michigan Alkali Div.

DOCTORS
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Bird Machine Company
Black Clawson Company
Downingtown Mfg. Co.
Lobdell United Co.
Lodding Engineering Corp.
The Moore & White Co.
Rice Barton Corporation
The Sandy Hill Iron & Brass Works
Shartle Brothers Machine Co.

DOCTOR BLADES
The Bagley & Sewall Company
Bird Machine Company
Lodding Engrg. Corp.
The Moore & White Co.
Rice Barton Corporation
The Sandy Hill Iron & Brass Works
Shartle Brothers Machine Co
Simonds Saw & Steel Co
Westinghouse Electric Corp.

DRIERS
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Beloit Iron Works
Biggs Boiler Works Co.
Black Clawson Company
Downingtown Mfg. Co.
Gibbs-Brower Company, Inc
Jackson & Church Co.
Lukenweld
The Moore & White Co.
Murray Mfg. Co., D. J.
J. J. Ross Company
Red-Ray Mfg. Co., Inc.
Rice Barton Corporation
Ross Paper Machy. Co.
The Sandy Hill Iron & Brass Works
Shartle Brothers Machine Co
Valley Iron Works Co.

DRIERS—LABORATORY
The Noble & Wood Machine Co.

DRILLED SUCTION COUCH ROLL
Manchester Machine Co.

DRILLED SUCTION DRUM ROLLS
Manchester Machine Co.

DRIVES
Appleton Machine Co.
The Bagley & Sewall Company
Beloit Iron Works
Bird Machine Co.
Black Clawson Company
Dodge Mfg. Corp.
Downingtown Mfg. Co.
Farrel-Birmingham Co.
Jeffrey Mfg. Co.
General Electric Company
Gibbs-Brower Company, Inc
Manchester Machine Co.
Moore & White Co.
Murray, D. J., Mfg. Co.
Pusey & Jones Corp.
Rice Barton Corporation
J. J. Ross Company
Ross Paper Machy. Corp.
The Sandy Hill Iron & Brass Works
Shartle Bros. Mch. Co.
Valley Iron Works Co.

DRUM WINDERS
Manchester Machine Co
Rice Barton Corporation

DRYER ROLL PYROMETER
Midwest Fulton Mch. Co.
Thwing-Albert Instrument Co.

DUSTERS
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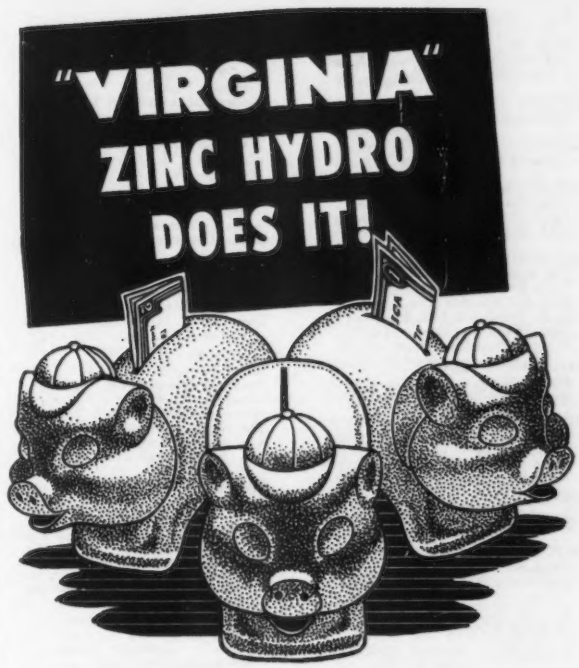
Downingtown Mfg. Co
Frank W. Egan & Co.
M. W. Jenkins Sons, Inc.
E. D. Jones & Son Co.
Moore & White Co.
D. J. Murray Mfg. Co
John Waldron Corp.

DUSTING BRUSHES
M. W. Jenkins Sons, Inc.

DYESTUFFS
American Cyanamid Company
Calco Chemical Div.
Ciba Company



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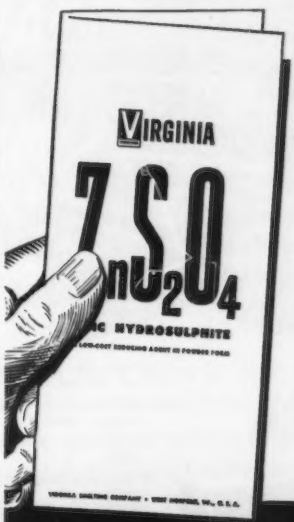
"Virginia" Zinc Hydro is widely used in the paper industry as one of the most *effective* brightening and decolorizing agents available for groundwood. "Virginia" Zinc Hydro is also one of the most *economical*. Please note the three important ways it contributes to economy: 1) its cost per ton of pulp is low; 2) the cost in capital investment of converting to its use is low; and 3) no auxiliary chemicals are required.



We urge your investigation of these economy claims for "Virginia" Zinc Hydro. When you find them to be soundly based, your interest in "Virginia" Zinc Hydrosulphite should be considerably whetted. Why not write today for a free test sample and our recommendations for its use.

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Egan, Frank W., & Co.
John Waldron Corp.

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Holyoke Machine Co.
B. F. Perkins & Son, Inc.
John Waldron Corp.
Wheeler Roll Co.

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Raymond, Chas. P., Service, Inc.

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Nopco Chemical Co.
Rohm & Haas Co.
Wyandotte Chemicals Corp

ENZYMES
Rohm & Haas Co.
Vanderbilt Co., R. T.

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Goslin-Birmingham Mfg. Co., Inc.
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Swenson Evaporator Co., Div. of Whiting Corp.
Westinghouse Electric Corp.

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B. F. Perkins & Son, Inc.
Ross Engineering Co., J. O
Westinghouse Electric Corp.

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Merrick Scale Mfg. Co.
The Permutit Company

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Huyck & Son, F. C.
Lockport Felt Co.
Morey Paper Mill Supply Co
Orr Felt & Blanket Co.
Shuler & Benninghofen
Waterbury Felt Co.
Waterbury, H., & Sons Co
Williams-Gray Co.

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Calgon, Inc.
General Dyestuff Corp
Nopco Chemical Co.

FELT CONDITIONERS
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The Noble & Wood Machine Co.
Rice Barton Corporation
The Sandy Hill Iron & Brass Works

FELT GUIDES
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Frank W. Egan & Co.
Gilbert & Nash Co.
Moore & White Co.
The Noble & Wood Machine Co.
Rice Barton Corporation
The Sandy Hill Iron & Brass Works
Shartle Brothers Machine Co.
Waldron Corp., John

FIBRE BOARD MACHINES
The Noble & Wood Machine Co.

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J. M. Huber Corp.
A. M. Meincke & Son, Inc.
Vanderbilt Co., R. T.
Wyandotte Chemicals Corp., Michigan Alkali Div.

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Bird Machine Company
Holyoke Machine Co.
Hungerford & Terry, Inc.
Improved Paper Machinery Corp.
Johnson Corp.
Moore & White Co.
J. O. Ross Engrg. Corp.
The Sandy Hill Iron & Brass Works
Walworth Company

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Crane Company
Grinnell Company
Shartle Bros. Mch. Co.
Walworth Company

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John Waldron Corp.
Westinghouse Electric Corp.

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Norton Co.

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Denver Equipment Co.

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Lukens Steel Co.
Rice Barton Corporation
The Sandy Hill Iron & Brass Works

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Elwell Parker Elec. Co.
Towmotor Corp.

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Williams Apparatus Co., Inc.

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Black Clawson Company
Downingtown Mfg. Co.
Manchester Machine Co.
The Moore & White Co.
Noble & Wood Machine Co.
Rice Barton Corporation
The Sandy Hill Iron & Brass Works
Shartle Brothers Machine Co

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Williams Apparatus Co.

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B. F. Goodrich Co.
The Goodyear Tire & Rubber Company

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De Laval Steam Turbine Co.
Downingtown Mfg. Co.
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Farrel-Birmingham Co.
E. D. Jones & Sons Co.
Moore & White Co.
D. J. Murray Mfg. Co.
Rice Barton Corporation
The Sandy Hill Iron & Brass Works
Shartle Brothers Machine Co.
Smith & Winchester Mfg. Co.
Valley Iron Works Co.
Westinghouse Electric Corp.
Western Gear Works

GRAPPLES
Blaw-Knox Company

GRAVITY FILTERS
Holyoke Machine Co.

GRINDERS
Carthage Machine Co.
Farrel-Birmingham Co.
Gibbs-Brower Company, Inc.
Hanchett Mfg. Co.
Lobdell United Co.
Norton Company
Samuel C. Rogers and Company
The Sandy Hill Iron & Brass Works

GRINDING WHEELS
Norton Company
Simonds Abrasive Co.

GUIDES
The Bagley & Sewall Company
Beloit Iron Works
Black-Clawson Co.
Egan, Frank W., & Co.
Gilbert & Nash Co.
The Moore & White Co.
Mount Hope Machinery Co.
Rice Barton Corporation
John Waldron Corp.

GUMMING MACHINES
Dilts Machine Works
Egan, Frank W., & Co.
The Sandy Hill Iron & Brass Works
Waldron, John, Corp.

GUMS
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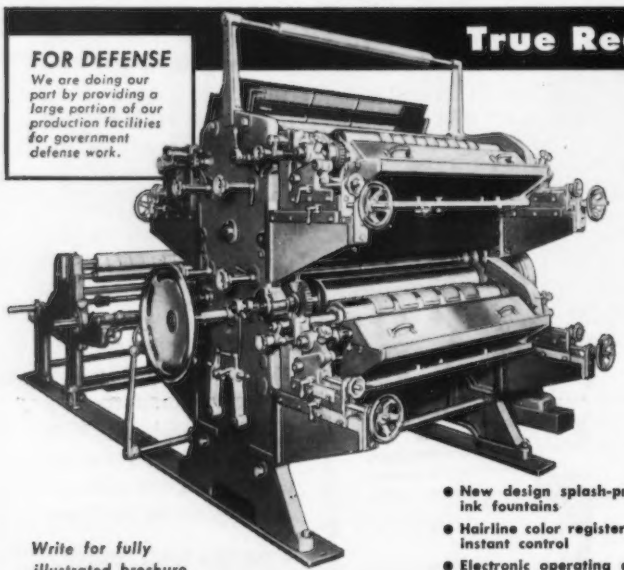
National Starch Products, Inc.

HEAT EXCHANGERS AND RECOVERY SYSTEMS
Westinghouse Electric Corp.

FOR DEFENSE
We are doing our part by providing a large portion of our production facilities for government defense work.

True Register—Cleaner Impressions



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Ross, J. O., Engrg. Corp.
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Nopco Chemical Co.
Wyandotte Chemicals Corp., Michigan Alkali Div.

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B. F. Goodrich Chemical Co.

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Testing Machines, Inc.
Thwing-Albert Instrument Co.
Tracerlab, Inc.
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Shartle Bros. Mch. Co.
Smith & Winchester Mfg. Co.
Valley Iron Works Co.

KILNS
Jackson & Church Co.
F. L. Smidth

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Dilts Machine Works, Inc.
Dusenbery Co., Inc.
Hamblet Machine Co.
E. D. Jones & Sons Co.
The Moore & White Co.
The Noble & Wood Machine Co.
Simonds Saw & Steel Co.
Taylor Stiles & Co.
Valley Iron Works Co.

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Black-Clawson Co.
Fibre Making Processes, Inc.
Improved Paper Machinery Corp.

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Thwing-Albert Instrument Co.

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Bauer Brothers Co.
Biggs Boiler Works Co.
Bird Machine Company
Dilts Machine Works
W. & L. E. Gurley
Egan, Frank W., & Co.
Hermann Mfg. Co.
Jackson & Church Co.
E. D. Jones & Sons Co.
Taylor Instrument Companies
Testing Machines, Inc.
Valley Iron Works Co.
John Waldron Corp.
Williams Apparatus Co., Inc.

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Dilts Machine Works
Egan, Frank W., & Co.
Rice Barton Corporation
John Waldron Corp.

LAY BOYS
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Shartle Bros. Mch. Co.
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Lobdell Co.
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NOZZLES
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Beloit Iron Works
Black-Clawson Co.
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Rice Barton Corporation
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Beloit Iron Works
Bagley & Sewall Co.
Black Clawson Company
Downingtown Mfg. Co.
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Thomas W. Hall Co.
Lukenweld
Manchester Machine Co.
Moore & White Co.
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Rice Barton Corporation
J. J. Ross Company
Ross Paper Machy. Corp.
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Rice Barton Corporation
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Hudson Sharp Machine Co.
Jagenberg-Werke Akt. Ges.
Langston Co., Samuel M.

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Leading machine builders often seek Sandusky's advice on centrifugal castings to fit new designs and new uses. They know that since 1907 Chief Sandusky has been headquarters for best information on non-ferrous centrifugal castings—especially castings for roll shells, liners, and covers. Sandusky's continuous program of research, both inside and outside its organization keeps this information always current—always up to the minute.

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Waldron Corp., John

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Biggs Boiler Works Co.
Crane Company
Grinnell Company
Michigan Steel Casting Co.
National Tube Co.
Walworth Company

PIPE FITTINGS
Armco Drainage & Metal Products, Inc.
Crane Company
Grinnell Company
Michigan Steel Casting Co.
Walworth Co.

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General Dyestuff Corp.
Monsanto Chemical Company
National Aluminate Corp.
Nopco Chemical Co.
Rohm & Haas Co.

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Aktivin Division, Heyden Chemical Corp.
B. F. Goodrich Chemical Co.
Naugatuck Chemical Division of U. S. Rubber Co.
Nopco Chemical Co.
Rohm & Haas Co.

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Lukenweld Division
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Black Clawson Company
E. D. Jones & Sons Co.
The Noble & Wood Machine Co.
Shartle Brothers Machine Co.

POPE TYPE REELS
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Egan, Frank W., & Co.
Manchester Machine Co.
Rice Barton Corporation

PRECISION SAMPLE CUTTER
Testing Machines, Inc.
Thwing-Albert Instrument Co.

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General Dyestuff Corp.

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Black-Clawson Co.
Goodrich, B. F., Company, Inc.
Manchester Machine Co.
Rice Barton Corporation

PRESSURE FILTERS
Holyoke Machine Co.

PRESSURE VESSELS
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Chicago Bridge & Iron Co.
Combustion Engineering-Superheater, Inc.
Jackson & Church Co.

PRESSES
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Black Clawson Company
Dietz Machine Works
Farrel-Birmingham Co.
Fibre Making Processes, Inc.
Gibbs-Brower Company, Inc.
Hudson-Sharp Mch. Co.
Jackson & Church Co.
Manchester Machine Co.
The Moore & White Co.
Potdevin Machine Co.
Rice Barton Corporation
The Sandy Hill Iron & Brass Works
Shartle Brothers Machine Co.
Valley Iron Works Co.
Waldron Corp., John
H. G. Weber & Co., Inc.
Williams Apparatus Co.

PULLEYS
Black-Clawson Co.
Dodge Mfg. Corp.
Rice Barton Corporation

PULP CLASSIFIER
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Thwing-Albert Instrument Co.

PULP CLEANERS
Bird Machine Co.
Nichols Engrg. & Research Corp.

PULP STOCK VALVES
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Grinnell Company
Record Fdy. & Mach. Co.
Rice Barton Research Corp.
Shartle Brothers Machine Co.

PULPERS
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Bauer Brothers Co.
Cowles Company
Dilts Machine Works
E. D. Jones & Sons Co.
Midwest Fulton Mch. Co.
Morden Machines Co.
The Noble & Wood Machine Co.
Rice Barton Research Corp.
Shartle Brothers Machine Co.

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Gottesman & Co., Inc.
Lyddon & Co. (America), Inc.
Nordicus, Inc.
Parsons & Whittemore, Inc.
Perkins-Goodwin Co.
Price & Pierce, Ltd.
Pulp and Paper Trading Co.
Pulp Sales Corp.
Restigouche Co., Ltd.

PULP SCREENS
Bird Machine Co.
Trimbey Machine Works

PULPSTONES
Norton Company

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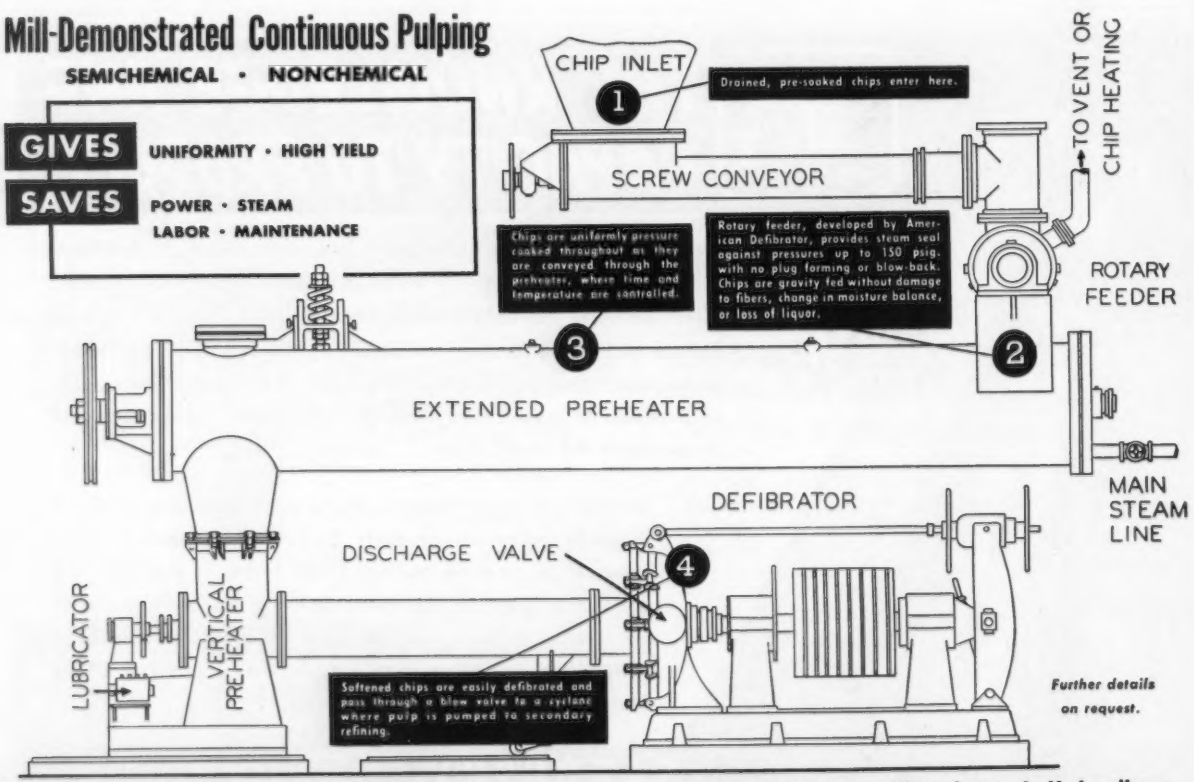
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1
Drained, pre-soaked chips enter here.
SCREW CONVEYOR
TO VENT OR CHIP HEATING
Chips are uniformly pressure cooked throughout as they are conveyed through the preheater, where time and temperature are controlled.
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3
2
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MAIN STEAM LINE
DEFIBRATOR
DISCHARGE VALVE
4
LUBRICATOR
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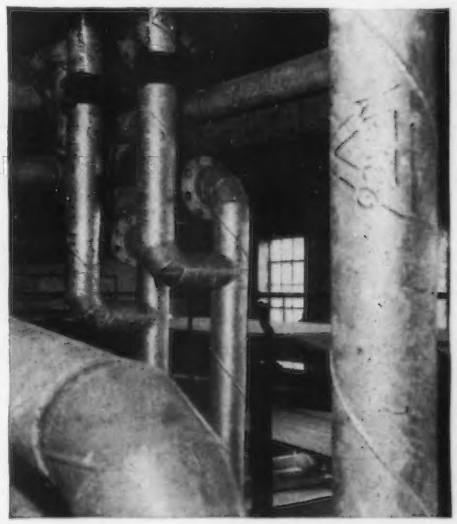

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"Continuous Beater & Refiner"

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Fifteen years ago a small Kraft Pulp Mill used a No. 1 Claflin Refiner on washed pulp ahead of screening. Washed pulp to Claflin to screen with accepted stock to wet machine chest and screen rejects back to digester and above cycle. Result, pulp required less time and power to repulp, beat and process than with other pulps.

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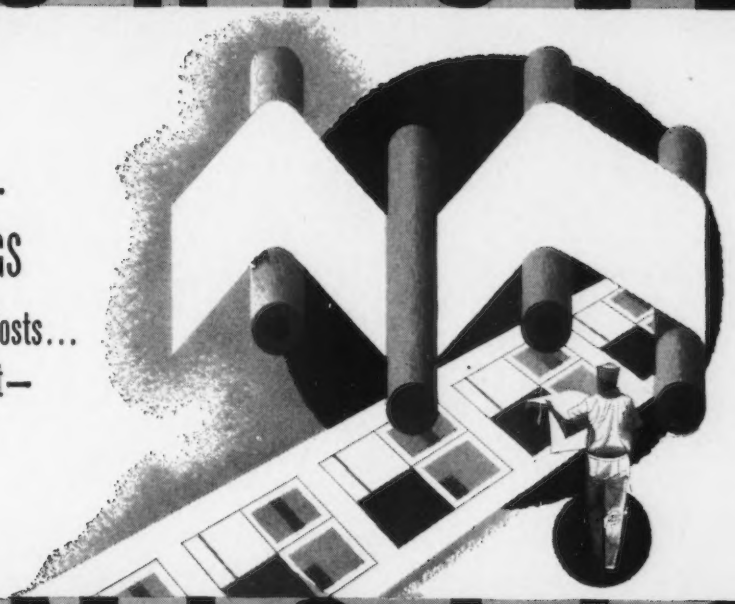

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